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Biology, fishery and status of the 2GH and 2J3KL (northern) cod stocks: information supporting an assessment of allowable harm under the Species at Risk Act for the COSEWIC-defined Newfoundland and Labrador population of Atlantic cod (*Gadus morhua*)

Biologie, pêche et état des stocks de morue du Nord de 2GH et de 2J3KL : information à l'appui d'une évaluation des dommages admissibles en vertu de la Loi sur les espèces en péril pour la population de morue (*Gadus morhua*) de Terre-Neuve-et-Labrador définie par le COSEPAC

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ABSTRACT

This paper reviews information on the biology, fishery and status of Atlantic cod (*Gadus morhua*) in the area from the northern tip of Labrador to the central Grand Bank (NAFO Subarea 2 and Divisions 3KL). This information was requested to assist in the assessment of allowable harm under the Species at Risk Act (SARA) for the COSEWIC-defined Newfoundland and Labrador population of cod. The COSEWIC population also includes cod on the southern Grand Bank (Divisions 3NO), but those cod are not discussed in the present paper. Information is presented separately for the 2GH and 2J3KL cod stocks. Little is known about the cod in 2GH, so the bulk of the information comes from the 2J3KL (northern) cod stock. In addition, because the dynamics of offshore and inshore populations of northern cod have differed since the collapse of the stock in the early 1990s, information is presented for offshore and inshore populations separately for the period from the mid-1990s to the present. As requested in the Terms of Reference for the assessment meeting, information is provided on the recent trajectory and current status of each stock. Targets for recovery of these stocks, and anticipated time frames to attain those targets, have not yet been formulated, so a few observations are provided regarding historic stock levels and the potential for stock growth. Data and estimates are provided regarding recent levels of landings and discards. Because the impact of these human-induced mortalities cannot be understood without consideration of the ecosystem within which the stocks are embedded, information is provided regarding the possible influence of predators (notably seals), prey (especially capelin) and the physical environment. The assessment of allowable harm is reported elsewhere.

RÉSUMÉ

L'information disponible sur la biologie, la pêche et l'état de la population de morue (*Gadus morhua*) retrouvée de la pointe nord du Labrador jusqu'au centre du Grand Banc (sous-zone 2 et divisions 3KL de l'OPANO) est évaluée dans le présent document. Cette information servira à l'évaluation des dommages admissibles en vertu de la *Loi sur les espèces en péril* (LEP) pour la population de morue de Terre-Neuve-et-Labrador définie par le COSEPAC. Cette population comprend aussi la morue du sud du Grand Banc (divisions 3NO), mais celle-ci n'est pas incluse dans le présent document. Les renseignements sur les stocks de 2GH et de 2J3KL sont présentés séparément. Peu de données sur le stock de 2GH ayant été recueillies, la plus grande partie de l'information porte sur le stock de morue du Nord (2J3KL). De plus, étant donné que la dynamique des composantes côtière et hauturière de ce dernier diffère depuis son effondrement au début des années 1990, l'information recueillie sur ces deux composantes du milieu des années 1990 jusqu'à aujourd'hui est présentée séparément. Tel qu'établi dans le mandat pour la réunion d'évaluation, de l'information est fournie sur la trajectoire récente et l'état actuel de chaque stock. Des cibles et des calendriers de rétablissement n'ayant pas été établis, quelques observations sur les niveaux historiques et les possibilités de croissance des stocks sont présentées. Des données et des estimations portant sur les niveaux récents des débarquements et des prises rejetées en mer sont aussi présentées. Étant donné que l'impact de ces sources anthropiques de mortalité ne peut être compris sans tenir compte de l'écosystème où sont enchâssés ces stocks, de l'information est incluse sur les effets possibles des prédateurs (les phoques notamment), des proies (le capelan en particulier) et du milieu physique. L'évaluation des dommages admissibles est présentée dans un autre document.

1 Introduction

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2003) grouped all cod from northern Labrador to the southern Grand Bank (Fig. 1) within a Newfoundland and Labrador population (or designated unit). This population was assessed as "endangered" and listed on Schedule 3 of the Species at Risk Act (SARA).

In the event that the population is listed on Schedule 1, SARA provides that the competent minister may issue a permit to allow for incidental harm in the period prior to establishment of a recovery plan, provided that a number of conditions are met.

Under section 73(2), authorizations may be issued only if:
(a) the activity is scientific research relating to the conservation of the species and conducted by qualified persons;
(b) the activity benefits the species or is required to enhance its chance of survival in the wild; or
(c) affecting the species is incidental to the carrying out of the activity.

Section 73(3) establishes that authorizations may be issued only if the competent minister is of the opinion that:
(a) all reasonable alternatives to the activity that would reduce the impact on the species have been considered and the best solution has been adopted;
(b) all feasible measures will be taken to minimize the impact of the activity on the species or its critical habitat or the residences of its individuals; and
(c) the activity will not jeopardize the survival or recovery of the species.

In respect to SARA Section 73, a scientific evaluation was carried out to identify potential sources of harm and to determine a level of incidental harm, if any, that would not jeopardize survival or recovery of cod in the Newfoundland and Labrador designated unit. The assessment is reported in an Allowable Harm Status Report (DFO 2004b). The purpose of the present paper is to document some of the details on the biology, fishery and status of much of the Newfoundland and Labrador population, as provided to the assessment meeting (Halifax; 25-28 October 2004).

As noted above, the "Newfoundland and Labrador population" of Atlantic cod includes all cod in Northwest Atlantic Fisheries Organization (NAFO) Divisions 2GHJ3KLNO (Fig. 1, 2). This area extends from just north of the northern tip of Labrador southward to beyond the continental shelf at the southern end of the Grand Banks of Newfoundland. The area includes the Labrador Shelf, the Northeast Newfoundland Shelf, Grand Bank (including Whale Bank) and a portion of Green Bank. Within this area, cod may be found from the landwash to almost 1000 m on the continental slope.

The cod from northern Labrador to the northern Grand Bank (Div. 2GHJ3KL) were at one time thought of as the Labrador – East Newfoundland stock complex (Templeman 1979, 1981). However, for management purposes, the cod in Div. 2GH have been considered separately from those in Div. 2J3KL since the early 1970s. The term "northern cod" is often used in reference to the 2J3KL stock, but sometimes the term has been used in reference to the whole Labrador – East Newfoundland complex (2GHJ3KL) (Smedbol and Wroblewski 2002).

The cod on the southern Grand Bank (3NO) have been managed as a third stock. This stock will not be discussed in the present paper.

There are also cod on Flemish Cap (Div. 3M). This is a relatively small bank east of the northern Grand Bank, from which it is separated by the 1000-1100 m depths of the Flemish Pass. The cod on Flemish Cap are the most distinct of all offshore populations of cod in the northwest Atlantic. There appears to be no interchange between cod on Flemish Cap and cod on Grand Bank. Flemish Cap cod were not included within the COSEWIC assessment.

For the purpose of assessing allowable harm to the "Newfoundland and Labrador population" of Atlantic cod, hereinafter referred to as cod, it is advantageous in the first instance to consider the three management stocks individually. This is because the bulk of the population analyses have been conducted at this level of aggregation since the early 1970s; the dynamics of the three stocks have followed different (although similar) trajectories over the past 3-4 decades; the vital rates of the fish vary geographically; and the human and non-human factors that might be affecting recovery of the fish vary geographically. An additional practical consideration is that two portions of the geographic distribution of the "Newfoundland and Labrador population" occur outside Canada's 200 nautical mile limit, and are therefore under fishing threat from countries other than Canada. The smaller of these areas is on the northeastern tip (the Nose) of Grand Bank within Division 3L (Fig. 2). The larger is toward the southern end of Grand Bank (the Tail of the Bank) within Divisions 3N and 3O.

It may be noted that assessment of these cod stocks was started in the early 1970s by the International Commission for the Northwest Atlantic Fisheries (ICNAF). After Canada's declaration of a 200 nautical mile limit in 1977, assessment of the 2GH stock was taken over by Canada. However, the 2J3KL stock continued to be assessed by NAFO, ICNAF's successor, until 1986, after which the stock was assessed by Canada. Because a portion of the 2J3KL stock area is within the NAFO Regulatory Area, occasional reviews were conducted by NAFO, and the results of the Canadian assessments were frequently presented to NAFO. Bishop and Shelton (1997) provide a detailed summary of the assessments of 2J3KL cod from 1977 to 1992. The 3NO cod stock continues to be assessed within NAFO (Healey et al. 2003).

The present paper first provides some background information on the biology and fishery of the 2GH and 2J3KL cod stocks (Section 2), and then provides information in response to six questions posed in the Terms of Reference for the meeting (Sections 3-8). The paper also includes six Appendices, which provide additional information on specific topics. The paper does not document information presented by participants other than the authors, nor does it document any of the discussion that took place during the meeting.

2 Description of Labrador – East Newfoundland Cod

This section provides an overview of the biology, stock structure and fishery of the cod in 2GH and 2J3KL.

2.1 Brief overview of biology

There is not much documentation specific to the biology of cod in 2GH, so most of this section refers to cod in 2J3KL.

2.1.1 Distribution

Distribution changes with age. Most scientific studies (Anderson and Gregory 2000; Lilly et al. 2000a) agree that the major nursery area for the northern cod stock is shallow water along the coast of southern Labrador and eastern Newfoundland, although young cod also occur on the plateau of Grand Bank. For the coastal areas, the young-of-the-year (age 0) cod are mainly inshore. By age 1 the cod start to appear in the offshore, and by age 3 or 4 they have a distribution that largely overlaps that of the older fish.

Historically, much of the northern cod stock overwintered near the shelf break in 300-500 m from Hamilton Bank in Div. 2J to the Nose of Grand Bank in Div. 3L. At some time in the spring most of these fish moved onto the shelf, and many of them migrated during late spring and summer into the shallow, coastal waters where they fed on capelin (*Mallotus villosus*) that had approached the coast to spawn (Templeman 1966; Lear et al. 1986). The cod then moved back across the shelf during the autumn. There is evidence from tagging studies (Rose 1993; Taggart 1997) that the fish that overwinter toward the edge of the southern Labrador Shelf and the Northeast Newfoundland Shelf approach the coast in a southwesterly direction, move northward while inshore, and then move back offshore, thereby completing clockwise circuits. The details are, of course, much more complex. For example, north-south oscillations were seen in both the offshore, winter habitat (Wroblewski et al. 1995; Taggart 1997) and the inshore, summer habitat (Taggart 1997). It is unclear whether the offshore-inshore migration pattern has persisted since the collapse of the offshore populations in the early 1990s.

Not all cod had this offshore-inshore migration pattern. For example, some cod moved during summer to feeding areas on the plateau of Grand Bank. Others spent the whole year in inshore waters, moving from deep inlets during winter to shallow feeding areas in summer. The aggregation that overwinters in Smith Sound (Fig. 4; see Appendix 1) moves northward during late spring and summer, and returns to the sound in late autumn or early winter.

Cod occur over a very broad depth range. They may be found in very shallow water, occasionally only a metre or two in depth, in inshore waters during late spring and early summer. They historically tended to occur at 300-500 m along the shelf break in winter, but have been found to 900 m or more (Baird et al. 1992b).

Cod have been found in water well below 0°C, even as low as -1.6°C (Colbourne et al. 2004), but most tend to occur in warmer water. The dense overwintering aggregations that at one time occurred toward the edge of the shelf were in 2-4°C water.

2.1.2 Spawning

A review by Fitzpatrick and Miller (1979) indicated that spawning occurred on the outer slopes of the continental shelf (Fig. 5). However, Hutchings et al. (1993) argued that this perception was based to a considerable extent on sampling that was biased toward the outer parts of the shelf. Their analysis of maturity data, collected over many years during winter-spring research surveys in offshore areas, found that cod in spawning condition (containing hydrated eggs) were not concentrated in the overwintering areas in deeper water but instead appeared to be primarily on the shelf (Fig. 6).

The dense concentrations of cod that at one time overwintered near the shelf break were frequently referred to as pre-spawning and spawning concentrations. Wroblewski et al. (1995) reported that cod in spawning condition were indeed caught in these aggregations. An ongoing question has been whether the cod actually spawn at their overwintering locations (essentially below the jet of the Labrador Current), or whether they move somewhat onto the shelf, perhaps through the channels, before spawning. Such movement might increase the likelihood that their eggs will remain on the shelf rather than be advected away. Pepin and Helbig (1997) provided a thorough review of the issue, and presented evidence that spawning may occur over the entire shelf.

Spawning also occurs on the plateau of Grand Bank (Hutchings et al. 1993; Ollerhead et al. 2004) and in inshore waters (Hutchings et al. 1993; Smedbol and Wroblewski 1997).

Cod in 2J3KL spawn over an extended period. There is a geographic cline, with cod in the north spawning earlier than those in the south. Templeman (1981) summarized various reports on the spawning of cod. With respect to the cod in 2GHJ3K, he stated that "most of the spawning of this stock occurs during March-May (mainly March-April) in deep water along the slope … there is also some later spawning in June in the deep channels and bank slopes closer to the coast … Cod spawning off northeast Newfoundland (Div. 3K) begins in March but occurs mainly in April to early May with some spawning continuing to June." He also stated that "on the northeastern Grand Bank (Div. 3L), spawning occurs mainly in April-June, but occasionally in years when temperature conditions are below normal spawning is delayed until May-July."

Spawning time of fish in the offshore was more recently determined from analysis of the spawning stage of cod that were visually examined during research trawl surveys (Myers et al. 1993b). The day of the year on which 50% of mature females were in a spent state was Julian day 97 ± 20 (April 7) for cod near Hamilton Bank (2J), Julian day 110 ± 28 (April

20) for cod near Belle Isle Bank (2J, 3K), Julian day 138 ± 36 (May 18) for cod near Funk Island Bank (3K), and Julian day 160 ± 37 (June 9) for cod in 3L (< 201 m). The authors thought that the method would over-estimate the mean spawning date by about 2 weeks. Hutchings and Myers (1994b) used a similar approach to examine inter-annual variability and found that spawning in 3L occurred on day 157 ± 18 (i.e. June 6).

2.1.3 Growth

Analyses of biological samples collected from the late 1940s to the early 1960s demonstrated a north-south cline in growth of cod in the Labrador-Newfoundland area. In general, growth rate and theoretical maximum length (L_∞ in the von Bertalanffy growth curve) were lowest off Labrador and highest on the southwestern Grand Bank (Fleming 1960; May et al. 1965). These differences were attributed by May et al. (1965) to differences in environmental temperature. They noted that there was a trend from north to south of increasing surface temperature and decreasing volume of cold Labrador Current water. Lilly (1982) postulated that seasonal access to prey might also be a factor. Cod off southern Labrador do not feed for a long period during the winter and spring, whereas cod on the northern Grand Bank have access to prey throughout most of the year.

Growth, as indicated by size-at-age of cod sampled during autumn surveys by Canada since 1978 in 2J3K and since 1981 in 3L, declined during 1983-1985 and again in the early 1990s, especially in 2J (Lilly, 2001; Lilly et al. 2003). Size-at-age has increased in recent years but is below peak values observed in the late 1970s. Much of the long-term variability in growth is associated with variability in water temperature (Krohn et al. 1997; Shelton et al. 1999).

2.1.4 Maturation

Analyses of biological samples collected during 1947-1950 demonstrated a north-south cline in maturation of cod in the Labrador-Newfoundland area (Fleming 1960). In general, both the age and length at maturation were lowest off Labrador and highest on the southwestern Grand Bank. The age at 50% sexual maturity (A_{50}) was 5.36 off Labrador (2HJ), 6.13 off the northern part of the Newfoundland coast (3K), 5.82 off the southern part of the Newfoundland coast (3L), 6.26 on the northeastern Grand Bank (3LN), and 7.47 on the southwestern Grand Bank (Div. 3O, with some 3N).

More recent information has come from analyses of samples collected during offshore research surveys by Canada. Morgan et al. (1994) calculated A_{50} and length at 50% maturity (L_{50}) by sex and Division from samples collected within each year (1978-1992 in 2J3K; from 1981 in 3L). They found that females matured at an older age and larger size than males. A_{50} for females did not differ significantly by Division, whereas the A_{50} for males increased from north to south. A_{50} for both males and females decreased over the period of sampling. For females, the decrease was from about 6.0 to about 5.5. The L_{50} for both females and males increased from north to south and decreased over the period of sampling. For females, L_{50} decreased from about 53 cm to 40 cm in 2J, from about 55 cm to 42 cm in 3K, and from about 57 cm to 47 cm in 3L. (Note that there was considerable annual variability, and these numbers are just approximations.) The declines in L_{50} were much more distinct than the declines in A_{50}.

Annual estimates of age at 50% maturity (A_{50}) for females from the 2J3KL cod stock as a whole have recently been calculated by cohort rather than by year, and have used data extending back to 1960 (Lilly et al. 2003). The estimated age at 50% maturity (A_{50}) was generally between 6.0 and 7.0 among cohorts produced in the mid-1950s and around 6.0 among those produced during the late 1960's to the early 1980s, but declined dramatically thereafter to a low of 5.0 for the 1989 cohort. Age at maturity remained low but variable for cohorts produced during the 1990s. Some of the high year-to-year variability in recent years may be caused by small sample sizes. Males tend to mature about one year younger than females.

Olsen et al. (2004) provide evidence supporting the hypothesis that the changes in the maturation schedule are a consequence of fisheries-induced evolution.

2.2 Stock Structure

Templeman (1962, 1979, 1981) used information from vertebral numbers, tagging studies, time and location of pre-spawning and other aggregations, times and places of spawning, and ancillary information such as growth pattern and relative year-class strength, to determine stock structure within Atlantic Canada. His Labrador – East Newfoundland stock complex, which was defined largely on the basis of high vertebral averages, occupied the area from northern Labrador to Div. 3L. The two northern divisions (2GH) have been managed as a separate stock since the early 1970s, in part because some of their characteristics, such as growth rate, appeared different from fish in 2J (ICNAF 1973), and in part because the severe fishing of the 1960s had a greater impact in 2GH than in areas to the south (Pinhorn 1976).

The 2GH and 2J3KL stocks are not isolated entities. There are very few cod north of Div. 2G on the North American side of the Labrador Sea and Davis Strait, but there is some support for the hypothesis that the northern Labrador Shelf may occasionally receive larvae from West Greenland (Templeman 1981; Dickson and Brander 1993). There is no evidence that this has happened to a significant degree for several decades.

There obviously has been intermingling between the 2GH and 2J3KL stocks. Indeed, as noted above, the distinction between the two is weak.

The 2J3KL cod stock intermingles with the 3NO stock on the plateau of Grand Bank, with the 3Pn4RS stock in the area of the Strait of Belle Isle, and with the 3Ps stock near the coastal region of 3L.

Numerous studies have indicated the likelihood of substock structure within the northern cod stock complex (see, for example, overviews by Lear 1986; deYoung and Rose 1993; Smedbol and Wroblewski 2002). The evidence includes a north-south cline in size-at-age and spawning time (see above), and a change in vertebral counts at approximately the north slope of Grand Bank. Cod tagged at specific locations in the offshore in winter tended to migrate to specific but broad areas of the inshore during summer and then returned to approximately the area of tagging in subsequent winters. It was also known that cod overwintered in various locations inshore and that some spawning occurred inshore.

After the stock as a whole collapsed in the early 1990s, it became clear that some aggregations of cod could still be found inshore. Tagging studies conducted during the collapse period indicate that the inshore of 3KL is inhabited by at least two groups of cod: (1) a northern resident coastal group and (2) a migrant group from inshore and offshore areas of 3Ps that moves into 3L during late spring and summer and returns to 3Ps during the autumn. It is not known if there is currently movement to the inshore from the offshore of 2J3KL.

Several sources of information are consistent with the hypothesis that there are distinct inshore or bay stocks along the east coast of Newfoundland. The information includes the presence of cod inshore in the winter, the historic existence of spring fisheries in the inner reaches of Bonavista and Trinity bays before cod arrived at the headlands from the offshore, the occurrence of spawning within the bays, and the paucity of returns offshore from cod tagged inshore in the winter. In addition, the aggregations sampled inshore since the mid-1990s by commercial fisheries, sentinel surveys, and research bottom-trawling (especially within Smith Sound in winter) contain a high proportion of individuals that are older and larger than those taken by research bottom-trawling in the offshore, especially in Div. 2J and 3K. See Appendix 1 for additional details regarding the biology and distinctiveness of cod in the inshore.

Genetic studies suggest that the northern cod conforms to an isolation-by-distance structure, with cod from more distant locations tending to be more distinct (Beacham et al. 2002). There appear to be differences between the inshore and the offshore, and among various areas of the offshore (Ruzzante et al. 1998; Beacham et al. 2002; but see Carr et al. 1995). Subpopulation structure at the level of individual bays is less strongly supported.

2.3 Brief overview of the fishery

The cod of Labrador and East Newfoundland have been exploited for centuries. Most of the landings have come from the 2J3KL stock, which historically was by far the largest cod stock in the northwest Atlantic.

2.3.1 2GH stock

Annual landings from the 2GH stock were relatively small (< 5,000 mt) during 1955-1964, but increased dramatically to an average of 73,000 t in 1965-1969, due to a pulse of fishing by non-Canadian fleets (Table 1; Fig. 7). Landings then declined to less than 5,000 t in most years during the 1970s and early 1980s, to less than 1,000 t during the latter half of the 1980s and to zero in 1991. The quota had been set at 20,000 t in 1974 and remained so until it was reduced to 1,000 t in 1993 and 200 t in 1995. The reduction in landings through the 1980s was due to the low availability of fish, not quota restriction. The stock was officially closed to directed commercial fishing in 1996.

2.3.2 2J3KL stock

Annual landings from the 2J3KL stock increased through the 18th and 19th centuries to about 300,000 t during the early decades of the 20th century. The early fishery was limited to shallow water. Deep waters ceased to be refugia in the 1950s, when longliners with powered gurdies were introduced to exploit cod in deep nearshore waters and distant water trawlers from Europe started to fish the deeper water on the banks. Landings increased dramatically in the 1960s as large numbers of trawlers located and exploited the overwintering aggregations on the edge of the Labrador Shelf and the Northeast Newfoundland Shelf. At the same time, the numbers of large cod in deep water near the coast of Newfoundland are thought to have declined quickly as the longliner fleet switched to synthetic gillnets. Total landings escalated from 360,000 t in 1959 to 810,000 t in 1968 (Table 2; Fig. 8), and then plummeted to 140,000 t in 1978. The landings by non-Canadian fleets declined substantially when Canada declared a 200 nautical mile fishing zone in 1977. Canadian trawlers soon replaced the non-Canadian fleets on the winter fishing grounds, and catches once again rose to above 200,000 t. In 1988-1989 it was recognized that the stock size had been overestimated for several years, and that fishing mortality during the 1980s had been higher than intended. Quotas were reduced, but not sufficiently to prevent an increase in fishing mortality. During the early 1990s the fishery experienced difficulty finding cod in the north. By the winter of 1992, the trawlers had difficulty finding fish anywhere. In July 1992 Canada declared a moratorium on directed cod fishing. Additional details on the history of the cod fishery of Newfoundland and Labrador, including changes in technology and temporal variability in the spatial distribution of fishing effort, may be found in many publications, including Templeman (1966), Lear and Parsons (1993), Hutching and Myers (1995), Lear (1998), Neis et al. (1999) and Hutchings and Ferguson (2000).

In 1998 a directed fishery was reopened for small (< 65 feet) vessels operating in the inshore. The quota was increased from 4,000 t in 1998 to 9,000 t in 1999, but was subsequently reduced to 5,600 t for 2001 and 2002 (Tables 2, 3; Fig. 9). Catches came primarily from the index/commercial fishery, but food/recreational fisheries made an important contribution in some years, most notably in 2001. When the fishery opened in 1998, good catch rates were experienced in many areas from the Baie Verte Peninsula in central 3K to St. Mary's Bay in southern 3L. However, in succeeding years the catches and good catch rates became increasingly concentrated in southern Bonavista Bay and northern Trinity Bay.

In the spring of 2003 it was announced that all of 2J3KL would be closed indefinitely to directed commercial fishing and recreational fishing. Sentinel surveys (see below) would continue. By-catch would continue, but at an unspecified level.

3 Present/recent species trajectory

3.1 2GH stock

Little is known about the historic and recent trends in biomass of the 2GH cod stock. Indeed, it is not clear that the stock is a discrete unit. Most of the fish caught in the area may have come from the most northern portion of the northern cod stock complex, which declined dramatically in the late 1960s due to intensive fishing. There have been no attempts since the early 1970s to conduct an analytical assessment because, as noted by Murphy et al. (1992), catch levels have been low, representative sampling data are not always available, and catch rate data are limited. The research surveys also are not very informative because coverage has been infrequent and often not at the appropriate season and depth. Murphy et al. (1992) provided abundance/biomass estimates from six surveys in the period 1978-1991, and Smedbol et al. (2002) provided a figure of biomass estimates from those surveys and additional surveys during the latter half of the 1990s. There was clearly a substantial decline in biomass from the early 1980s to the late 1980s, and no significant catches have been obtained in more recent surveys. It appears that the biomass of cod in this area is at an extremely low level.

3.2 2J3KL stock

The 2J3KL cod stock complex comprises populations in both the offshore and the inshore. Since the mid-1990s, the offshore populations have been at extremely low abundance, increasing the prominence of inshore populations and making it easier to discern their dynamics. These inshore populations appear to have been more productive than offshore populations since the collapse of the stock in the early 1990s, and it was these inshore populations that sustained a small directed cod fishery in 1998-2002.

The historic inshore fishery would have caught cod from the inshore populations and also from offshore populations that migrated to the inshore to feed on capelin. The bulk of the historic inshore catch came from these migrants. The inshore fishery will not return to its former prominence until such time as a substantial biomass of cod builds up once again in the offshore and these fish make summer feeding migrations to the inshore.

In this overview, the stock will be discussed as a unit for the period prior to the mid-1990s. For the period from the mid-1990s to the present, the cod in the inshore will be discussed separately from the cod in the offshore, partly in recognition of the different dynamics and partly as a consequence of the different sources of information.

3.2.1 Basis for historical and recent assessments.

Assessments up to 1993 were based on sequential population analysis (SPA) of the stock as a whole. SPAs are based on catch-at-age (commercial and food fisheries combined), and have been tuned in ways that have continuously evolved and have entailed the use of one or more series of commercial catch rates, research bottom-trawl indices, and sentinel survey indices. Sequential population analysis of the stock became problematic in the early 1990s and annual updates were discontinued for awhile after 1993. There have been several subsequent attempts at modelling the whole stock, including "illustrative" SPAs in 1998 and 2002, but these have not been accepted within the stock assessment process.

The problem that developed in the early 1990s was a lack of fit between SPA model output and the autumn research vessel index. The survey index declined precipitously during this period, and there is insufficient recorded catch to account for the decline. There are three classes of potential contributors to this lack of fit: the surveys may have overestimated the relative abundance of cod for several years; there may have been a substantial underreporting of landed and/or discarded fish; or a large quantity of fish may have died of natural causes (Shelton and Lilly 2000). To illustrate three of many possible scenarios for the history of this stock, the results of the 1993 assessment (Bishop et al. 1993) and two "illustrative" SPAs will be presented in this overview. One illustrative SPA retains the lack of model fit (Lilly et al. 1998b), whereas the other has sufficient unreported catch added to enable the model to fit the survey index. This latter model is based on the exploratory analyses of Shelton and Lilly (2000) and is described in Smedbol et al. (2002). Note that an assumption in this model is that there was a tremendous quantity of cod caught but not reported during the early 1990s. However, a similar result would have been obtained if it had been assumed that the "missing fish" died of natural causes.

The second problem that confounds assessment of the northern cod stock as a whole arose during the mid-1990s. For many years, the only fishery-independent index for this stock was that provided by the DFO autumn bottom-trawl survey. Although it was known that there was always some cod landward of the survey, it was assumed, not unreasonably, that the proportion of the stock landward of the survey was approximately the same every year. This clearly changed at some point during the early 1990s. Since about 1995 the quantity of cod in the inshore has represented a much higher proportion of the stock as a whole than had previously been the case. In addition, there have been larger and older fish caught in the inshore than have been caught in the offshore during the bottom-trawl surveys, especially in the 2J and 3K portion of the survey area. Thus, the research vessel survey has not represented a consistent portion of the stock as a whole during the period 1983-present. In 1995, new indices were started when sentinel surveys began monitoring catch rates with gillnet and linetrawl on traditional inshore fishing grounds. Although it is thought that these surveys provide useful indices of local inshore density, they may not reflect changes in the stock as a whole, since they do not extend into the broad expanse of the offshore.

Recent assessments have been based on a variety of sources, many of which are of relatively short duration. The major fishery-independent index has been derived from the DFO autumn offshore bottom-trawl surveys in 2J3KL. These surveys started in 1978, but for various reasons the index currently used is from 1983-present. There is also a DFO spring survey in 3L only (1985-present). Indices in the inshore have come from sentinel surveys with gillnets and linetrawls (1995-present), DFO bottom-trawl surveys in new inshore strata in 3KL (1996-present), and catch rates during commercial inshore fisheries (1998-2002). Tagging studies have provided estimates of exploitation rate and exploitable biomass in the inshore of 3KL (1999-2002). Hydroacoustic studies have provided estimates of biomass in Smith Sound (1995-present) and selected areas in the offshore. There have also been several series of studies of juvenile abundance in the inshore. A questionnaire completed by fish harvesters has provided opinion on changes in fish abundance over time and space.

During the 2003 assessment, a sequential population analysis for the inshore alone was conducted based on catches and indices from the inshore (1995-2002).

The COSEWIC assessment was based in part on the 2001 stock assessment (as documented in a Stock Status Report (DFO 2001a) and supporting research documents (mainly Lilly et al. 2001)), a Stock Status Update in 2002 (DFO 2002a), and some preliminary analyses presented during the 2003 assessment meeting. (Additional comment regarding the data used in the COSEWIC assessment is provided in Appendix 2.)

The following summaries of trajectory and current status are based on the 2003 assessment (as documented in a Stock Status Report (DFO 2003) and supporting research documents (mainly Lilly et al. 2003)) and a Stock Status Update in 2004 (DFO 2004a).

3.2.2 Trends in the stock as a whole (1962 – early 1990s)

3.2.2.1 Biomass

Total (3+) biomass of the stock as a whole collapsed from almost 3,000,000 t in 1962 to about 500,000 t in 1976, and then increased to just over 1,000,000 t in the mid-1980s (Fig. 10). There then followed a steady decline toward a crash in the early 1990s. The actual time course from the mid-1980s onward is somewhat uncertain, but the stock clearly reached an extremely low point by about 1994.

The spawner stock biomass (SSB) collapsed from about 1,500,000 t in 1962 to about 125,000 t in 1977, and then increased to 400-500,000 t through most of the 1980s (Fig. 11). The SSB declined rapidly after 1988, with perception of the time course varying among models.

3.2.2.2 Recruitment

Recruitment increased from about 700,000,000 individuals at age 3 for the 1959-1960 year-classes to a peak of almost 1,200,000,000 for the 1962 year-class, and then declined steadily to a low of about 140,000,000 for the 1970-1971 year-classes (Fig. 12). There were then 3 periods of moderately good recruitment. The last of these (the 1986 and 1987 year-classes) is of great interest. These year-classes appeared to be moderately strong when young, but they seemed to disappear rapidly. Perception of the strength of these year-classes, especially the 1987 year-class, varies considerably depending on the data and models that are chosen.

3.2.2.3 Natural mortality

Natural mortality has been assumed to be an instantaneous rate of 0.2 per year. As noted above, the catch reported for several years in the early 1990s is insufficient to account for the rapid decline in the bottom-trawl survey index. One possibility is that there was an increase in natural mortality at that time (see, for example, Lilly 2001).

3.2.3 Trends in the offshore alone (1983 - 2003)

3.2.3.1 Biomass

Trends in total abundance and biomass in the offshore are deduced from indices derived from the DFO autumn bottom-trawl surveys. The indices that have been routinely documented (e.g. DFO 2003, 2004) have been computed for those cod captured within "index" strata, which are those survey strata that have been occupied most consistently since the initiation of the autumn surveys. (These are strata in the offshore to a depth of 500 m in 2J3K and 200 fathoms (366 m) in 3L.) The indices (Fig. 13) were variable during the period 1983-1990, with one very strong positive outlier in 1986. The indices then declined very rapidly to reach a low in 1994. Values were slightly higher in 1999-2001 but have since declined (especially biomass). The average index of abundance in 2001-2003 was 3.6% of the average in the 1980s (1983-1988, excluding 1986), and the corresponding index of biomass was 1.8%.

Indices of spawner abundance and biomass in the offshore (Fig. 14) were derived from catches and sampling during autumn bottom-trawl surveys and commercial weights at age. Because the surveys were conducted during the autumn, it was thought that the population estimated in a given year would provide an appropriate basis for computing an index of the spawner population in the following spring. As described in Lilly et al. (2003), the spawner biomass on January 1 in year y was computed as

$$\sum_{a=1}^{20}(N_{a-1,y-1} \times Pm_{a-1,y-1} \times W_{a,y})$$

where N is population number, Pm is proportion mature, W is individual weight, a is index of age (a=1-20) and y is index of year (y=1984-2003). N was computed by areal expansion of the stratified arithmetic mean catch per tow in index strata in Div. 2J, 3K and 3L combined. Pm is the proportion of female cod that were mature, as estimated from a probit model fitted by cohort to observed proportions mature at age. W is the weight on January 1 as estimated from mid-year commercial weights. Weights derived from sampling of the commercial catch are used so as to be consistent with the weights used in the inshore SPA (see below). [Note that the computation of spawner biomass as described here differs from computation of the total biomass as illustrated in Fig. 13 in that it uses commercial weights-at-age, rather than the actual weights in the survey catches, and in extrapolation from a mean catch per tow rather than a summation of biomass estimates calculated for individual strata. (In some years, some strata were not surveyed.)]

The index declined quickly after 1990 to reach a minimum in 1995. There was a slight increase during the late 1990s and no trend during the past few years. Despite the increase in proportion of fish mature at age (Section 2.1.4) and an increase in commercial weights at age (Lilly et al. 2003), the average index of abundance in 2001-2003 was 1.7% of the average in the 1980s (1984-1989, excluding 1987), and the corresponding index of biomass was 1.5%. (Note that this spawner index has not yet been updated with survey data from the autumn of 2003.)

3.2.3.2 Recruitment

The index of recruitment derived from mean catch rate at age during the autumn bottom-trawl surveys (Fig. 15) shows the 1980-1982 year-classes to be relatively strong, and the 1986 and especially the 1987 year-classes to be equally strong. As noted above, this latter peak of young fish seemed to disappear rapidly and made only a very small contribution to the spawning stock. All year-classes since the very late 1980s have been very weak in the offshore.

3.2.3.3 Total mortality

Age specific mortality rates (proportion of population dying in a year) were calculated from catch rates during the autumn 2J3KL bottom-trawl surveys. The rates for all ages rose to very high levels by the early 1990s, and remained extremely high for a few years after the start of the moratorium in 1992 (Lilly et al. 2003). The paucity of older fish (7+) in the surveys since the early 1990s prevents estimating total mortality on these older ages. For younger ages, mortality has remained very high (Fig. 16).

To date it has not been possible to distinguish the relative contributions of fishing and natural mortality to this high total mortality. Reported by-catches in the offshore have been small (see section 8.2), so considerable attention has focused on the possibility that natural mortality is high. Most attention has been directed to the impact of predators (see Appendices 4 and 5).

3.2.3.4 Information from hydroacoustic studies

Trends in the biomass of cod are also available from hydroacoustic studies that have been conducted in two specific study areas in the offshore. Hydroacoustic studies were conducted in Hawke Channel in 2J in June 1994-1996 and 1998-2002. The biomass decreased by half from 1994 to 1995 and decreased further in 1996 (Anderson and Rose 2001). Biomass varied between 2,000 and 7,000 t during 1998-2002 (G. Rose, Memorial University of Newfoundland, St. John's, pers. comm.). Hydroacoustic studies have also been conducted at various times since 1990 in the channel between Funk Island Bank and Grand Bank, an area sometimes referred to as the Bonavista Corridor. Estimates from spring studies declined from about 450,000 t in 1990 to less than 25,000 t in 1993 (Rose and Kulka 1999) and to less than 5,000 t in 1994 (G. Rose, Memorial University of Newfoundland, St. John's, pers. comm.). Biomass in the area was extremely low through the mid-1990s, but increased somewhat in recent years (about 1,000 t in June 2000 and 2001 and about 9,000 t in June 2002) (G. Rose, Memorial University of Newfoundland, St. John's, pers. comm.). Most of the cod caught by bottom-trawling in support of the hydroacoustic surveys in recent years in Hawke Channel and the Bonavista Corridor have been younger than age 6 (G. Rose, Memorial University of Newfoundland, St. John's, pers. comm.).

3.2.4 Trends in the inshore alone (1995-2003)

Information on the size and behaviour of inshore populations started to accumulate only after the offshore populations declined to an extremely low level. By 1994 it appeared that there were no cod concentrations remaining in the 2J3KL area, but that perception changed in 1995 when a dense aggregation of cod was discovered in Smith Sound, Trinity Bay, and sentinel surveys started throughout 2J, 3K and 3L. The sentinel surveys were designed to provide catch rate information from traditional gears fished by commercial fish harvesters on traditional inshore fishing grounds. Hydroacoustic studies have been conducted on the Smith Sound aggregation annually to the present (although with some changes in methodology) and the sentinel surveys have also continued to the present. When it became apparent that an inshore fishery would be conducted in 1998, a tagging study which had started in 3Ps in 1997 was expanded to 3KL. This study, which continued until 2002, has provided information on exploitation rates and, together with information on catch, has enabled computation of the biomass of cod accessible to the fishery in each year. By 2003 it was thought that there was sufficient information to conduct a sequential population analysis for the inshore alone, using catch-at-age and indices from 1995-2002.

3.2.4.1 Hydroacoustic studies in Smith Sound

The hydroacoustic surveys conducted during winter in Smith Sound (western Trinity Bay) provided biomass estimates that increased from about 10,000 t in 1995 to about 26,000 t in 2001, and then declined to about 20,000 t in 2003 (Rose 2003; Lilly et al. 2003) and to 18,000 t in 2004 (DFO 2004). (Note that the perception of an increase of 16,000 t from 1995 to 2001 requires that an estimate of 21,000 t in April 1997 (Porter et al. 1998) be discounted.)

3.2.4.2 Sentinel surveys

Catch rates in the sentinel surveys in 2J and in 3K north of White Bay have been relatively low since the start of the surveys in 1995. However, fish have existed in sufficient density to enable moderate to high catch rates in some times and places from White Bay to the southern boundary of the stock. Catch rates declined almost everywhere after 1998. In 2003, the highest catch rates generally occurred in southern Bonavista Bay and Trinity Bay in northern 3L and in St. Mary's Bay in southern 3L adjacent to 3Ps. The sentinel survey data were standardized to remove site and seasonal effects and to produce annual indices of total catch rate for 3K and 3L combined. Gillnets and linetrawls were treated separately (Fig. 17). Gillnet catch rates increased from 1995 to 1998, declined to 2002 and increased a little in 2003. Linetrawl catch rates showed relatively little change from 1995 to 1996, increased in 1997, and then declined to a low in 2000. There has been variability in the past few years, with the 2003 value being similar to the 1998 value. However, the linetrawl catch comprised a higher proportion of small fish in 2003 than in 1998.

Note that the sentinel surveys provide information on spatial and temporal variability in cod density. However, it is not clear how they can be used to provide estimates of population abundance or biomass. They have been used, however, as tuning indices within the inshore sequential population analysis (see section 3.2.4.5).

3.2.4.3 Commercial/index fishery

Commercial/index fisheries were conducted during the summers and/or early autumns of 1998-2002. (See Lilly et al. 2003 for information on these fisheries, including management advice from the Fisheries Resource Conservation Council (FRCC), quotas and landings.) Catch rates in this fishery were calculated from catch and effort data recorded in logbooks maintained by commercial fish harvesters in the <35 foot sector (Fig. 18). Catch rates with gillnets, the predominant gear, were consistently low in 2J and northern 3K. During the period 1998-2002, catch rates declined in both southern 3K and southern 3L, and have remained high only in northern 3L, most notably in southern Bonavista Bay and northern Trinity Bay. The area over which high catch rates could be attained declined from 1998-2002.

The catch rate data were standardized to remove site and seasonal effects and to produce an annual index of catch rate for 3K and 3L combined. The index declined from 1998 to 2002 (Fig. 19).

3.2.4.4 Exploitation rate from tagging data

Two approaches have been employed to estimate exploitation rate from the tag return data. One method (Brattey and Healey 2003) estimates annual exploitation of the fish tagged within each tagging experiment. This calculation takes into account all recaptures, irrespective of where and when the recaptures occurred. The spatial and temporal patterns in exploitation rate are complicated (Lilly et al. 2003), but it may be noted that exploitation rates were much higher in 3K than in Trinity Bay. The second approach attempts to estimate the exploitation rate of cod within a specific area and time when the commercial fishery has been open. With this approach, the exploitation is calculated from the recovery rate of all fish that are estimated to be within the area during the specified period (Cadigan and Brattey 2003). The exploitation rates were estimated as the number of tagged fish caught and reported, divided by the number of tagged fish estimated to be available, with adjustments for reporting rate, tagging mortality and tag loss. The number of tagged fish available to be caught by a specific gear type within a specific area and time interval was estimated from the tagging data, individual growth, gear selectivity and a model of rates of movement of fish among areas. There were eight geographic areas in the model. Three of these are within the northern cod stock area: inshore Div. 3K, inshore northern Div. 3L (Bonavista and Trinity bays) and inshore southern Div. 3L (Conception Bay, the eastern

Avalon Peninsula, and St. Mary's Bay). Exploitable biomass was estimated for each of the three regions in 3KL for weeks in which reported landings were sufficient to provide reasonable estimates. The estimates for 2002 were 3,000 t for inshore 3K, 14,000 t for inshore northern 3L and 7,000 t for inshore southern 3L, for a total of 24,000 t. This was substantially less than estimates for 1999 (43,000 t), 2000 (47,000 t) and 2001 (59,000 t). Taken together, the estimates for the 4 years suggest that the biomass of cod available to the fishery in 3KL has been less than 60,000 t. However, it could be argued that the biomass has been even lower than that, since the estimate for 3K in 2001 was 24,000 t, or 40% of the 59,000 t estimate for the whole of 3KL that year. There is concern that this estimate for 3K may be high, since there were no tagging experiments in 2000 and 2001 prior to the fisheries that year (aggregations could not be located), and the increase in natural mortality applied to 3K still did not fully account for the substantial decline over time in the rate of recapture of fish tagged in 1999 and after the start of the fishery in 2000 (Cadigan and Brattey 2003). Additional information supporting a low biomass for 3K includes the decline in catch and catch rates, and the difficulty in finding fish to tag.

3.2.4.5 Inshore sequential population analysis (SPA)

The recent trend in biomass in the inshore is derived from a sequential population analysis (SPA) that incorporated catches and indices for the period 1995-2002. Stock biomass (ages 3-10+) decreased from about 60,000 t in 1996-1997 to less than 40,000 t in 2002, and then increased a little in 2003 (Fig. 10). Spawner biomass increased from 26,000 t in 1995 to 41,000 t in 1998, but subsequently declined to less than 15,000 t at the beginning of 2003 (Fig. 11). [It may be noted that the inshore SPA incorporated an assumption (based on analysis of tagging data) that the instantaneous rate of natural mortality was 0.5, which is much higher than the value of 0.2 that was used in the whole stock SPAs cited above.]

3.2.4.6 Recruitment

Analyses of catch rates at age in the sentinel surveys reveal that the 1990 and 1992 year-classes were stronger than other year-classes during the 1990s (Lilly et al. 2003). The relative strength of the 1992 year-class and the weakness of subsequent year-classes are also evident in output from the inshore SPA (Fig. 12). Year-class strength improved during the late 1990s (DFO 2004a).

3.2.4.7 Natural mortality

The exploitation rates estimated from tagging experiments that were conducted in Notre Dame Bay (3K) and Bonavista Bay (3L) tended to be high in the year of tagging and then to decline in subsequent years, even though exploitation rates from tagging in later years tended to be high in the year of tagging. This was more evident in 3K than in Bonavista Bay. One possible explanation for this phenomenon is that the proportion of the cod available to the fishery declined faster than estimated. This could be due to a movement out of the area, perhaps to the south or even to the offshore. A movement southward, perhaps to the Smith Sound population, is possible. A movement to the offshore seems unlikely, since very few cod of commercial size have been caught during the offshore research vessel surveys. A second possible explanation for the phenomenon above is that the level of natural mortality (assumed to be an instanteous rate of 0.2 per year) has been set too low. In contrast to findings in 3K and Bonavista Bay, exploitation rates from specific tagging experiments in Trinity Bay, and especially in Smith Sound, tended to increase over time. It seems that "disappearance" of cod was less noticeable for cod in Smith Sound.

This problem of the "disappearance" of cod was addressed by Cadigan and Brattey (2003), who made *ad hoc* adjustments to the level of natural mortality in their model to improve the fit between model output and the input data. They found that the best fit was achieved with an instanteous natural mortality of 0.8 in inshore 3K and 0.4 in both inshore northern 3L and inshore southern 3L. Note that this natural mortality, which is equivalent to an annual death rate of about 55% in 3K and 33% in 3L, was occurring on fish that were at least 50 cm at the time of tagging. (In consideration of such high mortality, an instantaneous natural mortality rate of 0.5 was used in the inshore SPA. This is equivalent to an annual death rate of 39% in the absence of fishing.)

4 Present/recent species status

4.1 2GH stock

The abundance/biomass of the 2GH stock is extremely low, but there is no estimate of the present size.

4.2 2J3KL stock

In the absence of a whole-stock SPA, there is no estimate of the abundance/biomass of cod currently in the whole of the 2J3KL stock area. Information will be presented for the offshore and the inshore separately.

4.2.1 Offshore

Over the most recent three years (2001-2003), the indices of total abundance and biomass computed from catches in the index strata during autumn bottom-trawl surveys have averaged 56.2 million individuals and 22.4 thousand t (Table 4). The actual population size remains unclear, because the length-specific catchability of cod has not been determined for the Campelen trawl in the 2J3KL area in the autumn. (Note that one measure of catchability is computed within SPAs. However, the last non-rejected SPA for this stock was tuned with catch rates from the Engel 145 trawl. Furthermore, the population estimated by that SPA would have included an unknown but possibly fairly large number of cod that were landward of the survey area at the time that the surveys were conducted. Interest here is on catchability of those cod that are actually within the survey area. There is an indication from other stocks that the catchability of the Campelen trawl may exceed 1 for cod.) The average index of abundance of cod in the past 3 years has been 3.6% of the average in the 1980s (1983-1988, excluding 1986), and the corresponding index of biomass has been 1.8%. The values in 2003 were 2.7% and 1.0% respectively.

The information provided above is based on the index strata alone. The autumn bottom-trawl survey has been conducted to 1000 m or more for most years since the early 1980s. Over the most recent three years (2001-2003), the abundance and biomass of cod in strata deeper than the index strata have averaged 2.0 million individuals and 1.6 thousand t respectively (Table 4). In addition, new strata have been occupied within the bays and adjacent to the coastline of 3KL since 1996 (excluding 1999). Over the most recent three years (2001-2003), the abundance and biomass of cod in the inshore strata have averaged 27.8 million individuals and 2.8 thousand t respectively (Table 4). Note that the average abundance is strongly influenced by catches of many small (age 1) cod in 3L in 2003.

The extent to which the inshore strata are monitoring the populations of cod that have been caught in the sentinel surveys and commercial and recreational fisheries in inshore waters is not known. Most of the recent inshore fisheries have been conducted in water depths shallower than those routinely fished during the surveys. The fisheries catch fish of ages and sizes that are not well represented in the surveys.

Over the most recent three years (2001-2003), the indices of spawners from the index strata have averaged 6.5 million individuals and 10.7 thousand t. The average index of spawner abundance in 2001-2003 was 1.7% of the average in the 1980s (1984-1989, excluding 1987), and the corresponding index of biomass was 1.5%. The values for 2003 were 1.6% and 1.3% respectively.

4.2.2 Inshore

The various measures of the relative or absolute quantity of cod within the inshore of 2J3KL in recent years have been based on several different methods conducted at different times of the year. They are not directly comparable to one another, but they are complementary.

As noted above, one may distinguish two major groups of cod within the inshore of 2J3KL in recent years. A third group cannot be distinguished at present.

(1) One group is the resident fish – those that spend the winter in 3KL. The largest overwintering population is that which is found in Smith Sound. Other overwintering populations occur in other deep inlets of western Trinity Bay and in inlets in Bonavista Bay (particularly in the southwest) and Notre Dame Bay. To date, no overwintering populations have been identified to the west and north of the Baie Verte Peninsula. [There is a small, resident, highly distinct population of cod in Gilbert Bay in southern Labrador (Green and Wroblewski 2000; Morris and Green 2002; Morris et al. 2003). Gilbert Bay has been identified as an Area of

Interest under the Oceans Act. The Gilbert Bay population will not be considered in this analysis.]

(2) The second group of cod within the inshore comprises those individuals that overwinter in 3Ps, migrate into 3L in spring or early summer, and migrate back to 3Ps in autumn or early winter.

(3) A third group, migrants from the offshore of 2J,3K and 3L, would at one time have been much larger than the other two, but this group is now very small. There has been no tagging in the offshore in recent years, so there is little information to help determine whether cod that overwinter offshore have been migrating to the inshore during recent summers.

The series of winter hydroacoustic surveys in Smith Sound has been surveying one overwintering population of resident cod. The biomass estimates of this population have declined from a high of 26,000 t in 2001 to 23,000 t in 2002, 20,000 t in 2003, and 18,000 t in 2004 (Rose 2003; DFO 2004a). There are additional populations elsewhere in 3KL, but there are no estimates of their magnitude. Each is thought to be much smaller than the Smith Sound population. It is thought that the overwintering resident populations in 3K suffered higher natural and fishing mortality during the late 1990s and early 2000s than the Smith Sound population, and that the 3K populations may currently be well below their levels in the late 1990s. However, these populations may now be experiencing improved recruitment.

The other estimates of the quantity of cod in the inshore of 2J3KL are based to a large extent on information that comes from the fishery. The fishery in 1998-2002 was conducted during summer and/or autumn, a time when most of the cod that overwinter in the inlets of 3KL move into shallower water and migrate along the coast. Some move in a direction that would ultimately take them southward, but most move northward. These resident cod are joined by cod from 3Ps. (There is also a possibility of movement of cod out of the northern Gulf of St. Lawrence through the Strait of Belle Isle, but this has not been identified in recent years.) Thus, population estimates derived from mark-recapture (tagging) studies and from sequential population analysis apply not just to the resident fish but to all cod that are within inshore waters at the time of the fishery.

The mark-recapture (tagging) study provided the following estimates for the biomass of fish available to the fishery in 2002, the most recent year of directed fishing: 3,000 t for inshore 3K, 14,000 t for inshore northern 3L and 7,000 t for inshore southern 3L, for a total of 24,000 t. This total was substantially less than estimates for the previous three years.

The sequential population analysis (SPA) provided estimates of the total (ages 3-10+) population for the beginning of 2002 of 43.0 million individuals and 36.4 thousand t and a spawning stock of 7.2 million individuals and 13.9 thousand t. Comparable values for the beginning of 2003 were 62.5 million individuals and 46.4 thousand t in the total (3-10+) stock and 8.3 million individuals and 14.0 thousand t in the spawning stock.

In summary, the quantity of cod estimated to be in the inshore in approximately mid-2002 was as follows: 20-23 thousand t for Smith Sound alone as estimated by hydroacoustics; 24

thousand t in the exploitable population as estimated from mark-recapture; and 36-46 thousand t of ages 3-10+ as estimated from sequential population analysis.

4.2.3 Stock as a whole

The estimates of abundance and biomass for the inshore and offshore have not been summed to provide an estimate for the stock as a whole. The reason for this is that, as noted above, there is no information on the catchability of the Campelen trawl (with respect to cod of various sizes in 2J3KL during the autumn). It is not even known whether the catchability is less than or greater than one.

In the absence of a single SPA spanning the period from 1962 to 2003, and the reluctance to combine the recent information on the inshore and the offshore, no estimate of the extent of the decline of the 2J3KL stock as a whole is provided in this paper. Note, however, that the COSEWIC (2003) report did provide estimates of the extent of the decline. A few comments on those values are provided in Appendix 2.

5 Expected order of magnitude / target for recovery

5.1 2GH stock

A target for recovery of the 2GH cod stock has not yet been formally discussed and documented.

There is very little information from which to determine historic levels of population size. If one assumes a 3+ population of about 310-320 million fish in 1964-1965 (ICNAF 1973) and an average individual weight of 0.8 kg (a little lower than the average of 0.83 kg computed from 3+ population numbers and biomass in the 2J3KL stock in 1964-1965, as estimated in the 1993 assessment), then the biomass in the mid-1960s, just before the severe overfishing by non-Canadian fleets, may have been about 250,000 t. A target for recovery would presumably be lower.

5.2 2J3KL stock

A target for recovery of the 2J3KL cod stock has not yet been formally discussed and documented.

An important issue is whether the stock is to be treated as a single unit or subdivided into two or more components. A level of subdivision that has been suggested is between inshore populations and offshore populations.

5.2.1 Whole stock considerations

5.2.1.1 Biomass

The whole stock sequential population analysis may be consulted for information on the historic levels of population size. Spawner stock biomass declined from about 1,500,000 t in 1962 to about 125,000 t in 1977, and then increased to 400-500,000 t through most of the 1980s. The SSB declined rapidly after 1988, reaching a low in about 1994-1995. The highest average biomass over any four consecutive years in the 1960s was 1,415,000 t compared with 431,000 t in the 1980s.

An attempt to define a limit reference point for spawning stock biomass (B_{lim}) was made during a meeting in November 2002 (Rivard and Rice 2002). It was decided that a B_{lim} could not be identified, but it was anticipated that the limit would have to be higher than 300,000 t for the stock as a whole. A target for recovery would presumably be greater than a B_{lim}.

Difficulty with establishing a B_{lim} was related primarily to the fact that certain B_{lim} candidates were "poorly defined by the historic stock-recruit data." It was stated that the data can be examined again when the SSB reaches 150,000 t, by which time there might be more data in the range in which information is scanty at present. A difficulty with this is that there may not be much catch in the offshore as the stock builds up toward the 300,000 t mark. Thus, there may not be a useful SPA with which one can gauge progress or explore B_{lim} candidates.

In the absence of an SPA, progress toward the target may have to be assessed from the indices of abundance and biomass derived from catches during the research bottom-trawl surveys. The relationship between SPA biomass and research vessel index has not yet been computed. (A difficulty is that the last non-rejected whole stock SPA for this stock was tuned with an index from the Engels 145 groundfish trawl, which was replaced with the Campelen 1600 shrimp trawl in autumn 1995.) It is also possible that SSB could be based on hydroacoustic surveys supplemented with trawling. Attention would have to be given to the comparability between biomass estimates from SPA and estimates from the hydroacoustics.

5.2.1.2 Distribution

As described in Section 2.1.1, a large portion of the 2J3KL cod stock historically migrated from offshore overwintering grounds to inshore feeding grounds. Opportunities for monitoring the return to historic distribution patterns may come from two sources; the resource assessment bottom-trawl surveys in the offshore during autumn, and sentinel, index or by-catch fisheries in the inshore during summer.

In the offshore during autumn, cod are currently broadly distributed at low density. See, for example, Fig. 20, which illustrates catch (kg) per standard tow during the 2001 and 2002 surveys. Similar plots for number per standard tow for 1995-2002 are provided by Lilly et al. (2003). The weight per standard tow in 2002 may be compared with the weight per standard tow averaged over the period 1980-1988 (Fig. 21). The two panels in this figure are not directly comparable, because the left panel is based on standard tows (30 min at 3.5 knots) with the Engel 145 trawl and the right panel is based on standard tows (15 min at 3.0 knots) with the Campelen 1800 shrimp trawl. Nevertheless, the difference is remarkable. A target for recovery might be a return to a pattern similar to that illustrated in Fig. 21 (left panel). This would include the presence of cod in abundance over much of the shelf, possibly with aggregations in four broadly defined areas (Lilly 1994): (1) from the northern limit of the survey to the coastal shelf off northern Newfoundland, especially the northern tip of Hamilton Bank and near the isthmus leading to Belle Isle Bank; (2) the outer trough between Belle Isle Bank and Funk Island Bank; (3) the outer trough between Funk Island Bank and Grand Bank, and from there southeastward along the northeastern slope of Grand Bank; and (4) the plateau of Grand Bank.

In the inshore during summer, cod are currently distributed throughout the area, but densities are very low north of White Bay. Highest densities are in Trinity Bay and Bonavista Bay. It is thought that the fish currently inshore have very low representation from migrating populations that overwinter offshore. As the offshore populations recover, one might expect to find relatively high summer densities (yielding good catch rates in test fisheries such as the sentinel surveys) in areas from central Labrador to the southern Avalon Peninsula. The distribution of such catches might be similar to that reported by Templeman (1958, 1966) (see Fig. 22a,b).

5.2.1.3 Size-age structure

The historic size/age structure varied from north to south, from shallow water to deep water, and from gear to gear. One can refer to length compositions from the 1930s (Thompson 1943) or the 1950s (Templeman and Fleming 1956, 1963). For example, Fig. 23 illustrates size composition by gear from the Bonavista area in 1950-1953. The fish caught on deep-water longlines tended to be much larger than those taken in traps, which were set in shallow water. The length composition of the deep-water fish peaked in the 60-80 cm range, but there were cod up to 100 cm and beyond. It is important to note that this length composition was obtained at the time that the deep waters off the headlands were just being opened following the introduction of longliners. During the next decade (1952-1962) the mean age of the deep-water longline catch off Bonavista declined from 13.4 years to 10.0 years, and the mean length declined from 76.4 cm to 67.4 cm (Fleming 1965). Commercial length and age compositions are more readily available from the 1960s onward. The catch at age matrix routinely reported in assessment documents (e.g. Lilly et al. 2003) includes good numbers of fish up to age 20 in the early to mid-1960s, but older fish were poorly represented during the late 1970s and 1980s, and declined dramatically during the early 1990s. There is also considerable information available from research vessel surveys from the 1970s onward. See, for example, Fig. 24, which illustrates the huge decline between the index of population numbers estimated for 1987 and that estimated for 1997. In this specific example, there were 160.4 million fish longer than 50 cm in 1987, but only 2.6 million in 1997.

5.2.2 Consideration of inshore populations separately

There is interest among some inshore fish harvesters in having small fisheries in the inshore alone. Directed commercial cod fisheries were indeed conducted during the summers and/or early autumns of 1998-2002. There is also interest among some members of the general public in having recreational/food fisheries in shallow, coastal waters. Recreational/food fisheries were open during the late summers or early autumns of many years during the period from 1994 to 2002.

5.2.2.1 Biomass

Defining a target for inshore populations will be problematic. It may be assumed that these populations have always existed, but that historically they were much smaller than the populations that migrated to the coast during the late spring and summer. Quantitative measures of the size of these inshore populations go back only to 1995. The current biomass is less than that observed during the late 1990s, so it is obvious that the inshore populations can be larger than they are at present. However, it is not known if they can grow beyond the level seen during the late 1990s.

As noted above, an attempt to define a limit reference point for spawning stock biomass (B_{lim}) for the stock as a whole was made during a meeting in November 2002 (Rivard and Rice 2002). No consideration was given to a B_{lim} for inshore components alone.

5.2.2.2 Distribution

A target for distribution of inshore populations will be problematic. The resident inshore populations that are known at this time or have been discussed in the past (see Appendix 1) occur from the inner reaches of Trinity Bay to western Notre Dame Bay. It is not known if these inshore resident populations can expand beyond their current distribution. The much broader distribution of the historic spring-summer catch, with the bulk of the catch taken at headlands and along open coasts (Fig. 22a,b) is primarily the distribution of the fish that migrated to the inshore from the offshore.

5.2.2.3 Size-age structure

It may be assumed that the inshore populations at one time had a size-age structure similar to the fish in the deep water off the headlands. Although the age structure of the fish currently in the inshore is not as broad as it was historically, the size structure is good, at least in Smith Sound in winter and in the area from Trinity Bay to eastern Notre Dame Bay in summer.

6 Time for recovery to the target

6.1 2GH stock

Because the cod off Labrador and eastern Newfoundland declined from north to south, it may be anticipated that rebuilding will occur from south to north. That is, recovery of cod in the inshore and offshore areas of 2GH may not be expected until after recovery is well under way in the northern parts of 2J3KL. As noted above, there is as yet no indication that recovery has started in the offshore of 2J3KL.

It is also possible that recovery on the northern Labrador Shelf could occur by reseeding from West Greenland. This seems unlikely, because data supporting previous arrivals of larvae from West Greenland are weak, and because the West Greenland cod stock is itself currently at a very low level.

6.2 2J3KL stock

6.2.1 Consideration of the offshore

There seems little possibility of recovery by rejuvenation of the cod that are currently in the offshore as long as total mortality remains as high as it has been since at least the mid-1990s. The mortality rate is so high that there has been no sustained improvement in the abundance/biomass or age/size composition of offshore populations during the decade since the collapse. Very few cod survive beyond age 5 and 50 cm.

The possibility of recovery of the offshore by immigration from adjacent areas is unknown. There are very few cod to the north in Div. 2GH, and the stock to the south (3NO) is at a low level. The potential for cod currently in the inshore to repopulate the offshore remains uncertain. Genetic studies using microsatellites have demonstrated a population substructure between most inshore and offshore areas. It has been suggested (Beacham et al. 2002) that this substructure indicates a low likelihood that inshore-spawning cod will contribute to offshore recovery. However, evidence of substructure may not preclude inshore-spawning cod playing a role in future offshore recovery. If fish currently in the inshore could recolonize the shelf, then allowing the inshore biomass to increase makes it more likely that inshore fish may move offshore. It may be noted, however, that to date there is no evidence of inshore-spawning fish moving to the offshore.

6.2.2 Consideration of inshore populations separately

6.2.2.1 Abundance/biomass

There can be no consideration of the time required for inshore populations to attain a target if there is no information regarding the historic magnitude of the inshore populations. However, it can be noted that the populations did increase from the mid-1990s to a peak in 1998 (as estimated for spawner biomass by the inshore SPA) or in 2001 (as indicated by hydroacoustic surveys in Smith Sound alone), and then declined. Recovery to the peak level seen in each series may be attainable within a decade, and probably less, provided there is good recruitment and low fishing mortality. However, the high level of natural mortality may preclude quick recovery, especially in the Notre Dame Bay populations. An important question is whether the inshore populations are currently sustaining the high levels of natural mortality that were estimated for the late 1990s and early 2000s.

6.2.2.2 Size-age structure

The populations in Trinity Bay and Bonavista Bay currently have a broad size structure and moderately broad age structure, as may be seen from sampling of catches from the commercial fishery and the sentinel survey (Lilly et al. 2003), sampling during hydroacoustic surveys in Smith Sound (Rose 2003), and sampling of fish that died during a mass mortality event in Smith Sound in April 2003 (J. Brattey, DFO, St. John's, pers. comm.). The growth of these inshore populations during the 1990s was largely a consequence of the recruitment and individual growth of two year-classes (1990 and 1992). These fish are now (in 2004) large and 12 and 14 years old.

7 Maximum human-induced mortality which the species can sustain and not jeopardize survival or recovery.

7.1 2GH stock

There is insufficient information on stock abundance/biomass to explore the consequences of various levels of human-induced mortality.

7.2 2J3KL stock

A major decision that must be made is whether this question is to be asked with respect to the stock as a whole, or whether the inshore can be considered separately from the offshore. Even if the emphasis is to be on the stock as a whole, it is still possible that one can assess whether some human-induced mortality can be sustained by inshore populations without affecting the rate of recovery of the offshore populations.

As noted above, a risk associated with fishing the inshore-spawning populations (as directed catch or by-catch) is that such fishing will slow growth of the inshore populations and reduce the possibility that they will spread to the offshore.

Another concern is that an inshore fishery will crop off production by the offshore populations. If the offshore populations do start to recover, and the cod continue to migrate inshore to take advantage of the rich feeding opportunities that the inshore historically provided, then some of those cod will be caught by the inshore fishery, as was the case for centuries. In addition, many of the cod that historically migrated to shallow inshore waters were immature, so the inshore fishery may capture some of those offshore fish before they have had a chance to spawn. Note that it may be possible to exploit the inshore populations and avoid catching migrants from the offshore if an inshore fishery is conducted between late autumn and early spring. This, of course, would be outside the traditional time for the bulk of the traditional inshore fishery.

With respect to the effect that an inshore fishery may have on inshore populations, the inshore SPA from the 2003 assessment has been used as a basis for projections (DFO 2003). The text from the 2003 assessment document (Lilly et al. 2003) is repeated here as a reminder of what was done. It was agreed during the assessment meeting that adding stochastic variation around the central trend would be unhelpful, and possibly misleading (Rice and Rivard 2003, their Annex 7). Instead, deterministic projections were conducted to provide an illustration of the medium-term possibility for the stock.

Projections were conducted under the assumption that stock productivity would not increase above recent levels. Projected values for weights-at-age and proportion mature at age were averages of values in 2000-2002. Natural mortality was assumed to be 0.5. Projected recruitment was based on the size of the spawner stock biomass (SSB) and was computed using the average R/SSB for the years 1995-2000. It is important to note that, for the projections, the size of the 2000 year-class at age 2 was reduced under the assumption that the SPA estimates were uncertain. The number at age 2 in 2002 was estimated based on the same average R/SSB value as was used to project the size of later year-classes. This resulted in a reduction in the numbers at age 2 in 2002 by 56% relative to the value in the SPA.

Projections conducted during the 2003 assessment indicated that if exploitation rates remain at recent levels (average F at age for 2000-2002), then the spawner biomass will grow slightly in the short term as a consequence of the incoming recruits, but will decline thereafter. There were no projections for specific TAC options. Projections also indicated that in the absence of fishing the spawner biomass would grow during the next decade, but would not reach the level attained in 1998. The projections were not illustrated in the documents from the meeting (DFO 2003; Lilly et al. 2003), but they may be seen in Shelton et al. (2003).

8 Potential sources of mortality/harm.

One can list various sources of human-induced mortality/harm, but an assessment of the impacts of such factors is difficult without a full understanding of other factors affecting productivity. Although fishing was a dominant factor in the collapse of the 2J3KL cod stock, it is difficult to assess the relative contributions of fishing and other factors to the final stages of the collapse from the late 1980s onward. A very brief overview of the possible role of the environment is provided in Appendix 3. In addition, numerous factors have been postulated to explain the lack of recovery since the moratorium was initiated in 1992. A brief overview of factors other than fishing is provided in Appendix 4. Additional detail on two of these factors, predation (predominantly by seals) and food supply (with emphasis on capelin), is provided in Appendices 5 and 6 respectively.

8.1 Directed fishing

8.1.1 Landings

A brief overview of the 2J3KL fishery is provided in the Introduction (Section 1.3). Landings are summarized in Table 2, which reports landings from 1959 to 2002, and Table 3, which provides additional detail on fixed gear landings. The landings data are those reported in the official statistics, with some exceptions, such as additions to the landings reported by distant-water fleets in some years (notably in Div. 3L) and the estimation of landings from the food/recreational fisheries in some years.

The fishery was under quota control from the early 1970s (Table 2; Fig. 8)), but the fixed gear sector operated under an allowance until the fishery was closed in 1992. Quotas were applied to the inshore for the first time when a directed fishery was reopened in 1998 for small (< 65 feet) vessels. The quota was set at 4,000 t in 1998, increased to 9,000 tonnes in 1999, but subsequently reduced to 7,000 t for 2000 and 5,600 t for 2001 and 2002 (Fig. 9). Landings during this period came primarily from the index/commercial fishery, but food/recreational fisheries made an important contribution in some years, most notably in 2001.

When the fishery opened in 1998, good catch rates were experienced in many areas from White Bay in central 3K to the southern limit of the stock area. However, in succeeding years the catches and good catch rates became increasingly concentrated in southern Bonavista Bay and northern Trinity Bay.

In the spring of 2003 it was announced that all of 2J3KL would be closed indefinitely to directed commercial fishing and recreational fishing. Sentinel surveys would continue. By-catch would continue, but at an unspecified level. Reported landings during 2003 were approximately 880 t from the commercial fishery and 90 t from the sentinel surveys, for a total of 970 t. Most (790 t) of the commercial landings came from a mass mortality of cod in Smith Sound, Trinity Bay, in April. The rest was by-catch in fisheries directed at other species. Most (84 t) of this came from gillnets set for winter (blackback) flounder.

The 2J3KL stock remained closed to directed commercial and recreational fishing in 2004. By-catch in the fishery for winter (blackback) flounder was considerably higher than in 2003 as fish harvesters took advantage of a change in the by-catch regulations.

By-catches of cod occur in ongoing Canadian and non-Canadian fisheries. All recorded by-catch has been added to the reported landings (Tables 2,3). The distinction between directed catch and by-catch is not always clear and may have little relevance when a directed fishery is permitted.

The quantities of cod landed from illegal activities (nonreporting, misreporting and poaching), and the quantities discarded from legal and illegal fisheries, have not been added to the catch data that have been used in the assessments. Thus, the historic population size and fishing mortality computed by sequential population analysis (SPA) are based solely on the reported landings (except in the few instances noted at the start of this section).

8.1.2 Fishing mortality

8.1.2.1 Historic fishing mortality

Instantaneous fishing mortality increased from about 0.3 in the early 1960s to above 1.0 just prior to the extension of jurisdiction (Fig. 25). It then dropped below 0.5 for a few years in the early 1980s before creeping up again through the mid-1980s. There was then a rapid escalation during the late 1980s and early 1990s. The perception of fishing mortality during this final collapse period (particularly during 1991 and 1992) depends on which stock trajectory is thought to be most representative, and whether it is thought that some of the very high total mortality during this period should be attributed to an increase in natural mortality. Whatever the perception, it is clear that there was a substantial increase in fishing mortality.

8.1.2.2 Recent offshore fishing mortality

As noted in the section on stock trajectory, the total mortality of fish in the offshore has remained very high since the collapse of the stock in the early 1990s. Year-classes are being produced, albeit at much lower numbers than prior to the 1990s. However, these year-classes disappear from the surveys at a very high rate. To date it has not been possible to measure the contribution of fishing to this apparently high total mortality.

There has been no directed fishery by Canada in the offshore since 1992. By-catches have come from trawl fisheries for northern shrimp and yellowtail flounder and both trawl and gillnet fisheries for Greenland halibut. The recorded by-catches in these fisheries are small. The discarding of small cod in the shrimp fishery was dramatically reduced with the introduction of the Nordmore grate in 1993 (Kulka 1998).

A by-catch of cod by non-Canadian fleets has been reported for the area outside the 200 mile limit on the Nose of Grand Bank in Division 3L. These catches are understood to be small (50-80 t annually in 2000-2002).

It is possible that the high mortality of "offshore" cod in recent years has been caused in part by captures inshore while the fish were on feeding migrations. However, this would be difficult to detect, since catches during offshore surveys have been too small to warrant tagging, and fish from the offshore would otherwise remain undetected in inshore catches.

Some people have asserted during assessment meetings and in other fora that by-catch and discarding in both domestic and foreign fisheries is under-recorded in official statistics. Any catches could be imposing important mortality, since there are so few cod in the offshore.

8.1.2.3 Recent inshore fishing mortality

Directed fishing was an important source of mortality in 1999-2002 (Fig. 25).

Some people have asserted during assessment meetings and in other fora that cod by-catch is under-recorded in official statistics. By-catches are common in gillnet fisheries for lumpfish and especially winter (blackback) flounder, and also occur in the herring gillnet fishery and the capelin trap fishery.

Additional unquantified sources of mortality include illegal fishing (poaching) and the fallout of dead cod from gillnets. The former is rumored to have been large in certain areas and times.

8.2 By-catch in fisheries directed at other species

In discussing by-catch, distinction may be made among landings that are recorded, landings that are not recorded, and discards.

8.2.1 Landings that are recorded

As noted above, by-catches of cod occur in ongoing Canadian and non-Canadian fisheries. All recorded by-catch has been added to the reported landings (Tables 2,3). The distinction between directed catch and by-catch is not always clear and may have little relevance when a directed fishery is permitted.

8.2.1.1 By-catch in the offshore (Canadian)

In the offshore, by-catches of cod by Canadian fleets have, in recent years, come from trawl fisheries for yellowtail flounder (Div. 3L) and both trawl and gillnet fisheries for Greenland halibut (Div. 3K, 3L). The recorded by-catches in these fisheries have been small (Table 5).

8.2.1.2 By-catch in the offshore (non-Canadian)

A by-catch of cod by non-Canadian fleets has been reported for the area outside the 200 mile limit on the Nose of Grand Bank in Division 3L. These catches are understood to be small (50-80 t annually in 2000-2002). Note, however, that these catches are larger than those reported for Canadian fleets in the offshore of 2J3KL.

8.2.1.3 By-catch in the inshore

In the inshore, by-catches are common in gillnet fisheries for lumpfish and especially winter (blackback) flounder (Table 6). They also occur in the herring gillnet fishery and the capelin trap fishery. Note that for winter flounder and herring there are both commercial fisheries and bait fisheries. The only inshore fishery that has been studied specifically for by-catch in recent years is the herring gillnet bait fishery, in which by-catches of cod appear to be small (Reddin et al. 2002).

8.2.2 Landings that are not recorded

This paper provides no comment on the level of non-reporting or mis-reporting in legal fisheries.

It is known that in recent years there have also been removals in inshore waters in excess of sentinel surveys and legal fisheries. The magnitude of such poaching is not known. It may be noted that the concept of poaching did not exist prior to the moratorium. (Indeed, it did not exist until unrestricted recreational fishing was terminated at the end of 1993.)

Prior to 1994, an unregulated food/recreational fishery with jiggers and baited hooks had existed since time immemorial. The quantity of fish taken for personal use each year was estimated and added to the commercial landings.

8.2.3 Discards

At one time there was considerable discarding in the offshore directed cod fishery (Kulka 1998) and in the inshore trap and handline fisheries (Hutchings and Ferguson 2000). There was also considerable dumping in some years associated with the oversupply of fish during the "trap glut" period.

The discarding of cod in the shrimp fishery was dramatically reduced with the introduction of the Nordmore grate in 1993 (Kulka 1998). Total discards from the large-vessel shrimp fishery in 2J3K were 5 t in 1995 and 13 t in 1996 (Kulka 1998).

Shrimp quotas increased dramatically during the late 1990s, and a new fleet of smaller trawlers entered the fishery in 1997. The level of observer coverage in this fleet of smaller vessels has been low (Orr et al. 2002). Therefore, the total quantity of discards may have increased since the mid-1990s, and the opportunities for observing such discards have declined.

The shrimp fishery has expanded into Div. 3L in recent years. The by-catch of cod in shrimp fisheries has been explored to a greater extent in Div. 3L than in areas further north. Orr et al. (1999) reported that there was little overlap between the distributions of small cod and shrimp during the autumns of 1995-1998, and Orr et al. (2002) estimated that the discards of cod by small and large shrimp vessels combined was less than 1 t annually during 2000 and 2001.

D. Orr (Fisheries and Oceans Canada, St. John's, NL, October 2004, pers. comm.) provided new estimates, specifically for the present paper, of the discards of cod by large and small Canadian shrimp vessels in 2GH, 2J3K and 3L for the years 1997-2003 (Table 7). The procedure used was similar to that described for the estimation of by-catch of Greenland halibut in the same fisheries (Bowering and Orr 2004). Estimates for 2GH were much less than 1 t in each year. Estimates for 2J3KL were below 5 t in each year.

There is no information on the discarding of low quality cod caught in gillnets, and the discarding of small cod caught by handlining.

8.2.4 Incidental mortality

The harmful effects of fishing are not limited to those fish that are captured and either landed or discarded. Other categories of mortality (ICES 2004) that might be occurring include escape mortality (individuals that escape from fishing gear but subsequently succumb to injury from contact) and drop-out mortality (individuals that die in the gear but drop out before the gear is landed on the deck). In addition, there is concern that trawling might induce stress and fatigue and ultimately death in fish that avoid the gear.

8.2.5 The impact of unaccounted fishing mortality

The following two paragraphs are from the research document supporting the 2003 assessment (Lilly et al. 2003).

In the offshore, cod appear to experience an extraordinarily high mortality rate. The extent to which this is attributable to mortality associated with unreported catch, discards and injury caused by contact with gear (e.g. shrimp trawls) is not known. However, any such deaths may be important because the abundance of cod in the offshore is so very low.

In the inshore, the magnitude of unreported by-catch and poaching is not known, so their impact cannot be assessed. However, there is concern that such catches may be impeding recovery, especially in 3K, where the local cod populations appear to have been greatly depleted compared to levels during the late 1990s.

8.3 Fisheries on food supplies

Capelin has long been considered to be vital to the well-being and migrations of cod in 2J3KL. Capelin is also fished commercially. Appendices 4 and 6 contain overviews of the capelin fishery and the links between capelin and cod.

Cod also prey upon shrimp and small snow crab. Both species have increased in abundance since the 1980s, probably in part due to the release in predation pressure attending the collapse of cod and other groundfish. The impact that fisheries for shrimp and crab might be having on cod has not been assessed, but the impact may be small at this time of low cod abundance and high crustacean abundance.

8.4 Scientific research

Cod are caught and killed during research bottom-trawl surveys in 2H, 2J3KL and 3NO in the autumn and 3L and 3NO in the spring. The proportion of the cod within the survey area taken during the bottom-trawl surveys is small, as illustrated by the following. The area covered by a standard tow is about 0.007269 square nautical miles. The area of the index strata in 2J3KL is 87,593 square nautical miles. The number of tows made during each survey is about 500. Thus, the percentage of the survey area covered by the trawl is ((0.007269/87,593) * 500 * 100), or about 0.0041%. If we assume that the trawl catches every cod in its path, then the survey will catch 41 individuals out of every million.

The actual number of cod captured during the autumn surveys in 2J3KL, including the inshore strata where some relatively large catches have been taken, has averaged 3584 individuals during the period 2001-2003.

From the above, it is concluded that the research bottom-trawl surveys capture a negligible number of cod.

There is some additional capture of cod during studies for other purposes. This includes beach seining to study the productivity of juvenile cod, and bottom-trawling in nearshore waters to study the habitat of juvenile cod. The number of cod killed during such work has not been examined.

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NOTE: Since 1990, more than 200 peer-reviewed scientific papers and numerous research documents have discussed some aspect of the status or biology of northern cod. A list of these documents may be obtained upon request from George Lilly, Fisheries and Oceans Canada, P.O. Box 5667, St. John's, NL A1C 5X1 (tel: 709 772-0568; email lillyg@dfo-mpo.gc.ca).

Table 1. Landings (t) of cod from NAFO Divisions 2GH for the period 1954-2002. (updated from Murphy and Bishop 1995)

Year	Canada	Other	Total	TAC
1954	1,654	45	1,699	
1955	743	22	765	
1956	146	32	178	
1957	963	0	963	
1958	1,585	943	2,528	
1959	1,321	1,831	3,152	
1960	1,000	7,000	8,000	
1961	1,000	3,000	4,000	
1962	1,199	3,735	4,934	
1963	930	3,084	4,014	
1964	829	8,318	9,147	
1965	1,217	63,028	64,245	
1966	1,311	92,878	94,189	
1967	4	56,131	56,135	
1968	523	83,894	84,417	
1969	320	63,297	63,617	
1970	75	17,712	17,787	
1971	7	12,632	12,639	
1972	4	13,686	13,690	
1973	3	294	297	
1974	0	4,070	4,070	20,000
1975	7	6,952	6,959	20,000
1976	39	5,890	5,929	20,000
1977	41	3,617	3,658	20,000
1978	37	4,821	4,858	20,000
1979	126	2,054	2,180	20,000
1980	106	2,512	2,618	20,000
1981	405	3,245	3,650	20,000
1982	3,252	10,259	13,511	20,000
1983	265	2,116	2,381	20,000
1984	252	1,279	1,531	20,000
1985	229	318	547	20,000
1986	345	149	494	20,000
1987	8	126	134	20,000
1988	496	0	496	20,000
1989	449	0	449	20,000
1990	431	16	447	20,000
1991	0	0	0	20,000
1992	0	0	0	20,000
1993	0	0	0	1,000
1994	0	0	0	1,000
1995	0	0	0	200
1996	0	0	0	0
1997	0	0	0	0
1998	0	0	0	0
1999	0	0	0	0
2000	0	0	0	0
2001	0	0	0	0
2002	0	0	0	0
2003	0	0	0	0

Table 2. Landings (t) of cod from NAFO Divisions 2J3KL for the period 1959-2002. (from Lilly et al. 2003)

	2J				3K				3L				2J3KL			
	Offshore mobile gear		Fixed gear		Offshor mobile gear		Fixed gear		Offshore mobile gear		Fixed gear					
Year	Canada	Other	Canada	Total	Canada	Other	Canada	Total	Canada	Other	Canada	Total	Total Canada	Total Other	Total	TAC
1959	0	46372	17533	63905	0	97678	56264	153942	4515	51515	85695	141725	164007	195565	359572	
1960	1	164123	15418	179542	53	74999	47676	122728	7355	63985	94192	165532	164695	303107	467802	
1961	1	243144	17545	260690	0	64023	31159	95182	4675	73899	70659	149233	124039	381066	505105	
1962	0	226841	23424	250265	0	47015	42816	89831	4383	90276	72271	166930	142894	364132	507026	
1963	1	197868	23767	221636	0	79331	47486	126817	4446	83015	73295	160756	148995	360214	509209	
1964	13	197359	14787	212159	0	121423	40735	162158	10158	142370	75806	228334	141499	461152	602651	
1965	0	246650	25117	271767	21	50097	26467	76585	7353	130387	58943	196683	117901	427134	545035	
1966	39	226244	22645	248928	13	58907	32208	91128	8253	120206	55990	184449	119148	405357	524505	
1967	28	217255	27721	245004	114	78687	24905	103706	13478	200343	49233	263054	115479	496285	611764	
1968	4650	355108	12937	372695	1849	119778	40768	162395	15784	211808	47332	274924	123320	686694	810014	
1969	30	405231	4328	409589	56	80949	24923	105928	18255	151945	67973	238173	115565	638125	753690	
1970	0	212961	1963	214924	92	78274	21512	99878	14471	137840	53113	205424	91151	429075	520226	
1971	0	154700	3313	158013	31	61506	21111	82648	11976	148766	38115	198857	74546	364972	439518	
1972	0	149435	1725	151160	7	133369	14054	147430	4380	109052	46273	159705	66439	391856	458295	
1973	1123	52985	3619	57727	108	159653	13190	172951	1258	97734	24839	123831	44137	310372	354509	666000
1974	0	119463	1804	121267	19	149189	10747	159955	880	67918	22630	91428	36080	336570	372650	657000
1975	410	78578	3000	81988	189	112678	15518	128385	670	53770	22695	77135	42482	245026	287508	554000
1976	94	30691	3851	34636	771	79540	20879	101190	2187	40998	35209	78394	62991	151229	214220	300000
1977	525	39584	3523	43632	1051	26776	28818	56645	5362	26799	40282	72443	79561	93159	172720	160000
1978	4682	17546	6638	28866	7027	6373	29623	43023	9213	12263	45194	66670	102377	36182	138559	135000
1979	9194	6537	8445	24176	21572	16890	27025	65487	14184	12693	50359	77236	130779	36120	166899	180000
1980	13592	7437	17210	38239	21920	6830	37015	65765	15523	13963	42298	71784	147558	28230	175788	180000
1981	22125	4760	14251	41136	23112	3847	23002	49961	21754	15070	42827	79651	147071	23677	170748	200000
1982	58384	8923	14429	81736	8881	4074	42141	55096	27181	9271	56490	92942	207506	22268	229774	230000
1983	37276	4158	10748	52182	31621	2815	40683	75119	39123	10920	55001	105044	214452	17893	232345	260000
1984	9231	2782	13150	25163	48114	11059	35143	94316	47668	15973	49351	112992	202657	29814	232471	266000
1985	1466	78	10211	11755	68880	12945	30368	112193	36863	31176	39306	107345	187094	44199	231293	266000
1986	5734	7859	12916	26509	62086	5781	28384	96251	57805	53946	32202	143953	199127	67586	266713	266000
1987	39344	3999	16022	59365	39686	6160	27442	73288	44612	25916	36743	107271	203849	36075	239924	256000
1988	41468	9	17112	58589	40260	50	33820	74130	57805	26748	51405	135958	241870	26807	268677	266000
1989	33626	1003	23304	57933	37350	1179	20711	59240	40958	36621	59238	136817	215187	39803	253990	235000
1990	17883	183	14505	32571	26920	504	27516	54940	31187	25488	75266	131941	193277	26175	219452	199262

cont'd

Table 2. (cont'd)

	2J				3K				3L				2J3KL			
	Offshore mobile gear		Fixed gear		Offshore mobile gear		Fixed gear		Offshore mobile gear		Fixed gear					
Year	Canada	Other	Canada	Total	Canada	Other	Canada	Total	Canada	Other	Canada	Total	Total Canada	Total Other	Total	TAC
1991	621	82	2214	2917	30112	311	13332	43755	30264	49660 [2]	45416 [3]	125340	121959	50053	172012	190000
1992	0	0	18	18	584	273	884	1741	13627	14610 [4]	10960 [5]	39197	26073	14883	40956	0
1993	0	0	13	13	0	0	541	541	2	2425 [6]	8411 [7]	10838	8967	2425	11392	0
1994	0	0	9	9	0	0	368	368	0	1	936	937	1313	1	1314 [8]	0
1995	0	0	0	0	0	0	94	94	0	0	237	237	331	0	331 [9]	0
1996	0	0	3	3	0	0	739	739	1	1	655	656	1398	1	1398 [10]	0
1997	0	0	3	3	0	0	159	159	4	0	339	343	505	0	505	0
1998	0	0	16	16	0	0	1993	1993	1	6	2490	2497	4501	0	4507	4000
1999 [1]	0	0	36	36	0	0	3644	3644	0	1	4792	4793	8472	1	8473	9000
2000 [1]	0	0	5	5	0	0	1459	1459	13	54	3888	3955	5365	54	5419	7000
2001 [1]	0	0	21	21	0	0	1735	1736	7	82	5124	5212	6887	82	6969	5600
2002 [1]	0	0	13	13	0	0	647	647	3	50	3533	3586	4196	50	4246	5600

[1] Provisional catches.

[2] Includes French catch and other foreign catch as estimated by Canadian surveillance.

[3] Figure is 4000 t less than Canadian statistics (this quantity is considered 3NO catch misreported as 3

[4] Derived from reported catch and Canadian surveillance estimate of foreign catch.

[5] Includes 5000 t catch from the recreational fishery after the moritorium was declared.

[6] Canadian surveillance estimate of foreign catch .

[7] Includes 5053 t estimated for the recreational fishery additional to that recorded by Canadian statistics.

[8] 1300 t is from the food fishery; the remainder is bycatch

[9] Includes 163 t caught in the sentinel survey and 168 t caught as bycatch.

[10] Comprised of a sentinel survey catch of 397 t, a food fishery catch of 962 t and bycatch of 142 However, 103 t of sentinel catch remains to be allocated by division and gear.

Table 3. Fixed gear landings (t) by Division and gear type in Divisions 2J, 3K and 3L in 1975-2002. Landings from statistical areas other than Newfoundland are not included. (from Lilly et al. 2003)

	2J					3K					3L					2J3KL
Year	Trap	GN	LL	HL	Total	Trap	GN	LL	HL	Total	Trap	GN	LL	HL	Total	Total
1975	642	2304	0	54	3000	4662	8645	565	1646	15518	10390	7552	1641	3112	22695	41213
1976	1022	2787	6	36	3851	7056	10666	718	2439	20879	18404	9066	2904	4835	35209	59939
1977	1285	2076	37	125	3523	11501	11611	1294	4412	28818	20988	8852	3591	6851	40282	72623
1978	2872	3376	55	335	6638	11329	11445	3647	3202	29623	23218	9023	5114	7839	45194	81455
1979	1333	5663	175	1274	8445	3532	11474	8414	3605	27025	20785	13488	7022	9064	50359	85829
1980	4679	11414	204	913	17210	12732	13549	8059	2675	37015	12871	11231	9394	8802	42298	96523
1981	3893	10105	72	181	14251	3952	10679	6360	2011	23002	10177	13579	11425	7646	42827	80080
1982	4464	9121	114	730	14429	16415	17571	6101	2054	42141	24248	20295	5704	6243	56490	113060
1983	3870	4854	842	1182	10748	10490	18305	2560	9328	40683	25690	16446	3834	9031	55001	106432
1984	5618	6116	379	1037	13150	9957	14362	2499	8325	35143	23103	14985	3824	7439	49351	97644
1985	4973	2992	252	1994	10211	13310	8082	2352	6624	30368	21594	8760	3245	5707	39306	79885
1986	4373	7804	109	630	12916	14555	7626	1555	4648	28384	15669	9865	2492	4176	32202	73502
1987	5158	9228	218	1418	16022	11278	10223	1590	4351	27442	11370	17419	3338	4616	36743	80207
1988	5907	9183	272	1750	17112	16261	11898	935	4726	33820	22148	18576	4004	6677	51405	102337
1989	6713	14846	290	1455	23304	8189	7921	700	3901	20711	23964	22231	4676	8367	59238	103253
1990	3616	9364	653	872	14505	11201	7726	3838	4751	27516	32158	28936	4545	9627	75266	117287
1991	1016	271	93	834	2214	7696	1384	1851	2401	13332	26524	11696 [2]	1247	5949	45416 [2]	60962
1992	0	0	2	16	18	27	103	9	745	884	1173	1131	16	8640 [3]	10960 [3]	11862
1993	0	0	1	12	13	3	37	9	492	541	11	93	80	8227 [3]	8411 [3]	8965
1994	0	0	0	9	9	0	8	0	359	367	6	38	22	870	936	1312
1995	<1	<1	0	0	0	13	52	28	2	95	12	176	33	16	237	332
1996	0	0	0	3	3	25	132	17	565	740	18	219	15	404	656	1500 [4]
1997	0	3	0	0	3	22	101	34	1	159	33	257	29	21	339	501
1998	0	3	5	8	16	24	1081	245	644	1994	31	1377	284	798	2490	4501
1999 [1]	0	21	3	12	36	4	3030	106	503	3644	4	4310	60	419	4792	8472
2000 [1]	0	4	0	1	5	15	1126	43	275	1459	63	2954	189	684	3891	5354
2001 [1]	0	3	1	17	21	28	796	90	822	1735	175	2844	110	1994	5124	6880
2002 [1]	0	7	0	6	13	2	272	30	342	647	128	2517	30	858	3533	4193

[1] Provisional catches.

[2] Catch is 4000 (t) less than Canadian statistics as this quantity is considered 3NO gillnet catch misreported in 3L.

[3] Estimate for recreational fishery has been reported as 3L Handline.

[4] Comprised of sentinel survey catch of 294 t, a food fishery catch of 1155 t and by-catch 142 t. An amount of 103 t must still be allocated by gear type and division from the sentinel catches.

Table 4. Abundance and biomass of cod estimated to be in Divisions 2J, 3K and 3L combined, as computed by areal expansion of the stratified arithmetic mean catch per tow during autumn research bottom-trawl surveys in 2001-2003. Index strata are those strata in the offshore to a depth of 500 m in 2J3K and 200 fathoms (366 m) in 3L. The deeper strata are those on the upper continental slope deeper than the index strata. The inshore strata are those that were added within the bays of 3KL starting in 1996. (from Lilly et al. (2003))

	Abundance (millions)				Biomass (thousand t)			
Grouping	2001	2002	2003	Average	2001	2002	2003	Average
Index strata	63.3	62.4	42.9	56.2	31.2	23.0	12.8	22.4
Strata deeper than index strata	1.4	1.8	2.9	2.0	1.2	1.3	2.4	1.6
Inshore strata	21.5	8.4	53.5	27.8	3.2	2.1	3.0	2.8
Total	86.2	72.6	99.2	86.0	35.6	26.5	18.2	26.8

Table 5. Recorded landings (t) of cod in offshore Canadian fisheries directed at other species, by Division and year (1996-2004). Data for most recent years are provisional.

Division	Year	Angler	Atlantic halibut	Other	Redfish	Skate	Greenland halibut	Witch flounder	Yellowtail flounder
2J	1996						0.0		
	1997						0.0		
	1998						0.1		
	1999						0.0		
	2000								
	2001								
	2002								
	2003								
	2004								0.2
3K	1996			0.7			0.7		
	1997			54.5			0.2		
	1998			0.4		0.1	0.0		
	1999				0.2		0.5		
	2000		0.1	0.5			61.4		
	2001			1.1		0.0	16.1		
	2002			1.4		0.0	0.3		0.0
	2003			0.0			0.2	0.0	0.0
	2004			0.0			6.2		0.2
3L	1996			9.2		0.0	0.0	0.0	
	1997			77.2	0.2		0.3		
	1998			0.0		9.3		0.0	
	1999		0.0	1.7			0.1		
	2000			2.2			37.3		
	2001		0.0	1.1		0.2	28.7	0.1	13.2
	2002		0.0	0.1		0.1	4.1	0.0	4.4
	2003	0.3	0.0	1.0		0.0	0.1	0.0	2.7
	2004		0.0	0.2		0.0	2.2		2.0

Table 6. Recorded landings (t) of cod in inshore Canadian fisheries directed at other species, by Division and year (1996-2004). Data for most recent years are provisional.

	3K		3L	
Year	Blackback flounder	lumpfish	Blackback flounder	lumpfish
1996	0.2	0.1	1.5	0.9
1997			0.5	
1998	2.7		35.6	
1999	0.0		0.7	
2000	4.4	0.2	16.8	2.1
2001	2.6	0.2	10.6	5.3
2002	0.7	0.0	8.7	0.7
2003	4.1	0.0	92.0	6.5
2004	111.9	0.0	370.7	19.5

Table 7. Estimated discards (t) of cod from the large vessel (> 100 feet) and small vessel (< 100 feet) shrimp fisheries in 2GH, 2J3K and 3L during 1997-2003. Estimates provided by D. Orr (Fisheries and Oceans Canada, St. John's, NL, October 2004, pers. comm.).

	Large vessels			Small vessels	
	2GH	2J3K	3L	2J3K	3L
1997	0.12	3.26		0.25	
1998	0.13	1.38		0.47	
1999	0.16	2.01		2.58	
2000	0.13	1.48	0.10	1.35	0.00
2001	0.03	1.47	0.23	1.39	0.26
2002	0.04	0.51	0.14	1.49	0.15
2003	0.03	0.79	0.06	2.85	0.99

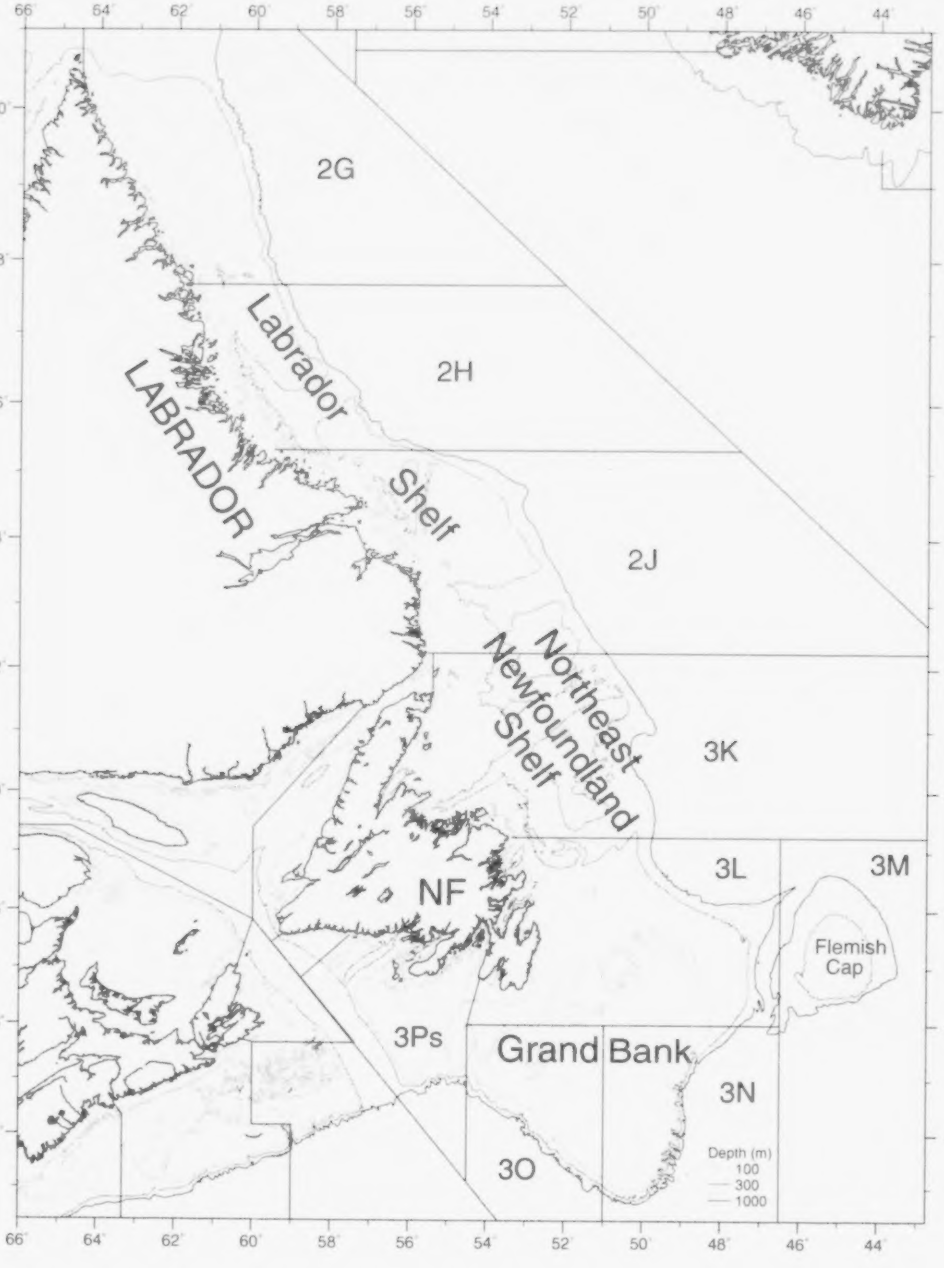
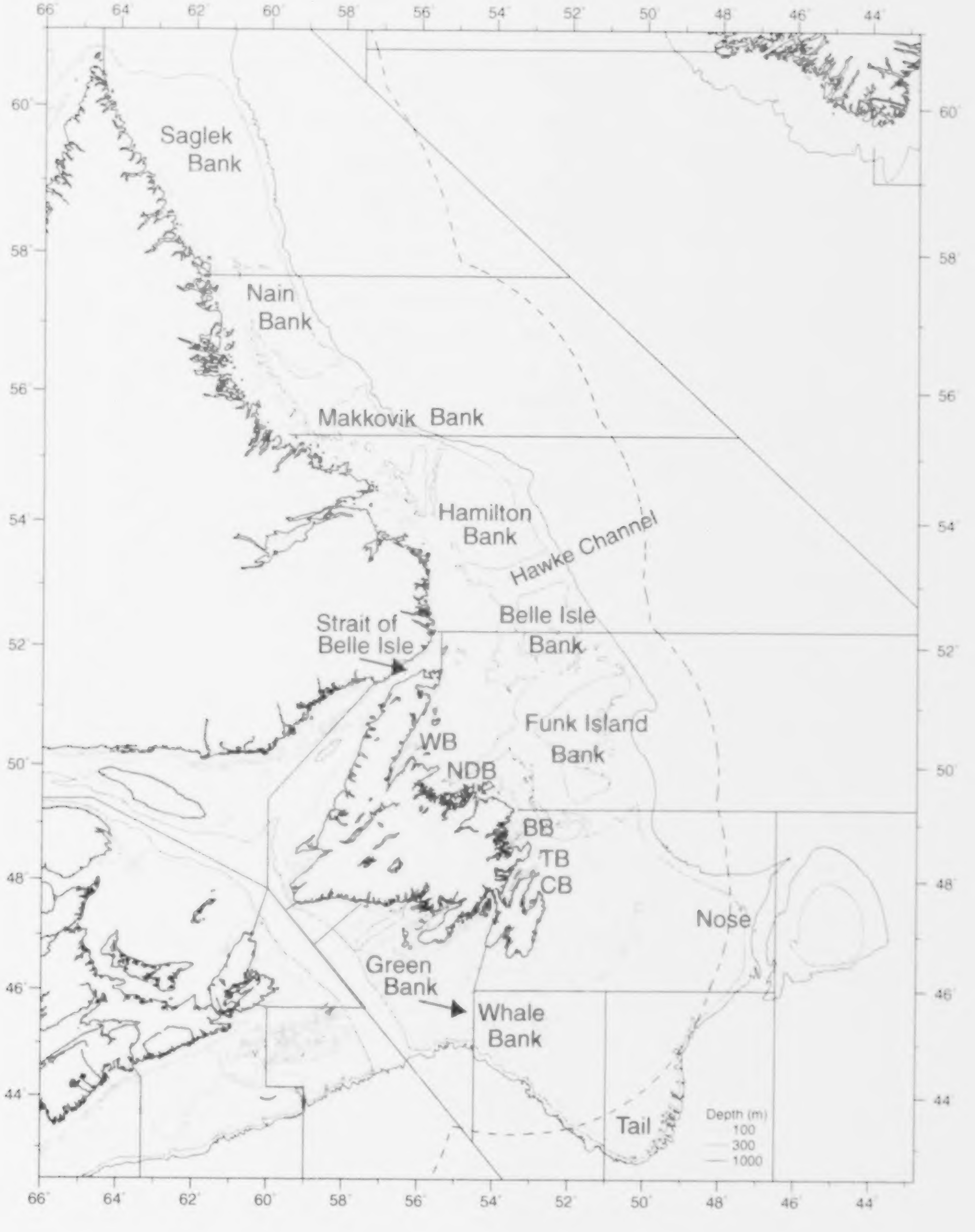

66°
64°
62°
60°
58°
56°
54°
52°
50°
48°
46°
44°
2G
Labrador
2H
LABRADOR
Shelf
2J
Northeast
Newfoundland
Shelf
3K
3L
3M
NF
Flemish
Cap
3Ps
Grand Bank
3N
3O
Depth (m)
100
300
1000

Fig. 1. Map of the Labrador-Newfoundland area, illustrating major geographic features and NAFO Divisions and Subdivisions.



Saglek Bank
Nain Bank
Makkovik Bank
Hamilton Bank
Hawke Channel
Belle Isle Bank
Strait of Belle Isle
Funk Island Bank
WB
NDB
BB
TB
CB
Nose
Green Bank
Whale Bank
Tail
Depth (m)
100
300
1000
66°
64°
62°
60°
58°
56°
54°
52°
50°
48°
46°
44°

Fig. 2. Map of the Labrador-Newfoundland area, illustrating the location of Canada's 200 nautical mile limit and various banks and bays. The bays, from north to south, are White Bay (WB), Notre Dame Bay (NDB), Bonavista Bay (BB), Trinity Bay (TB) and Conception Bay (CB).

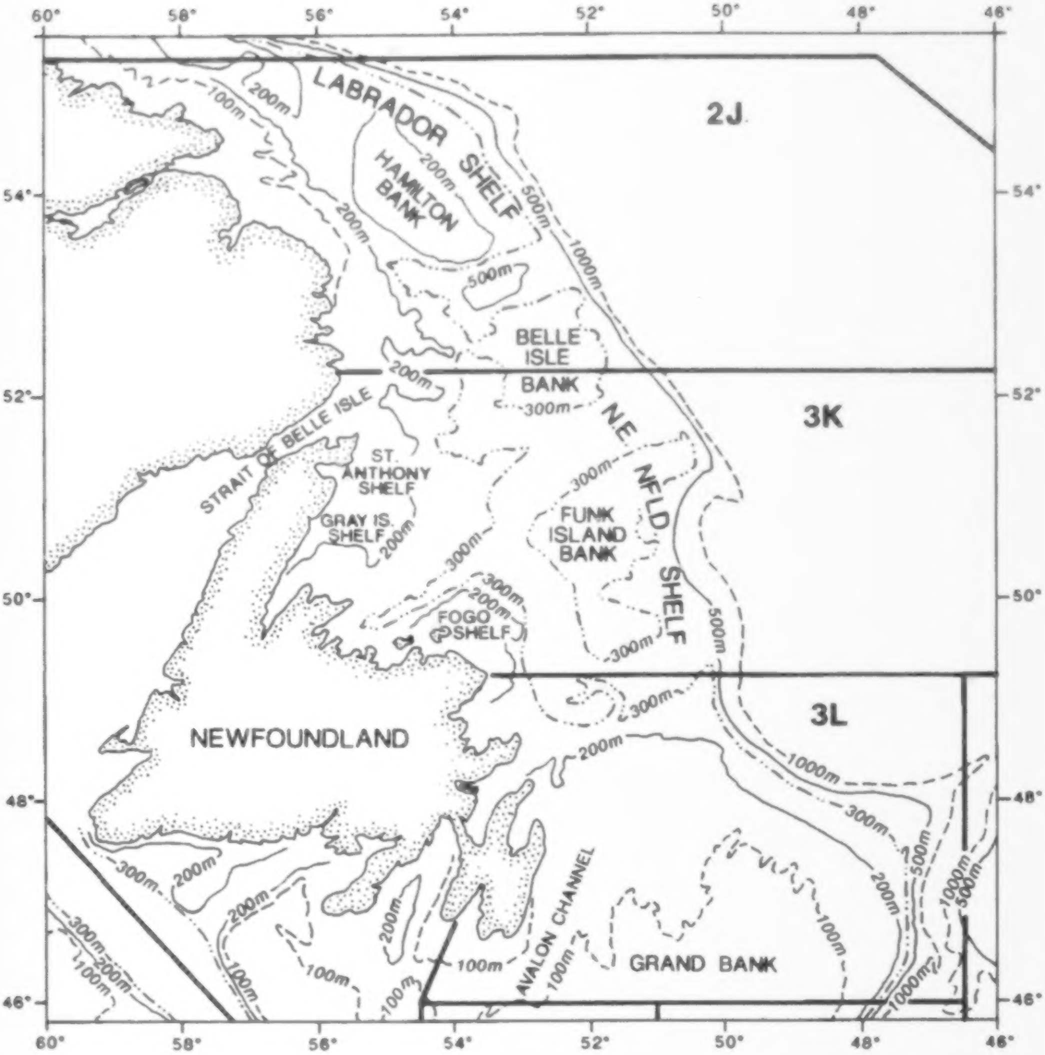

60°
58°
56°
54°
52°
50°
48°
46°
54°
52°
50°
48°
46°
2J
3K
3L
LABRADOR SHELF
HAMILTON BANK
BELLE ISLE BANK
NE NFLD. SHELF
STRAIT OF BELLE ISLE
ST. ANTHONY SHELF
GRAY IS. SHELF
FUNK ISLAND BANK
FOGO SHELF
NEWFOUNDLAND
AVALON CHANNEL
GRAND BANK
100m
200m
300m
500m
1000m

Fig. 3. Map of the shelf area off southern Labrador and eastern Newfoundland, illustrating NAFO Divisions and locations of some geographic features.

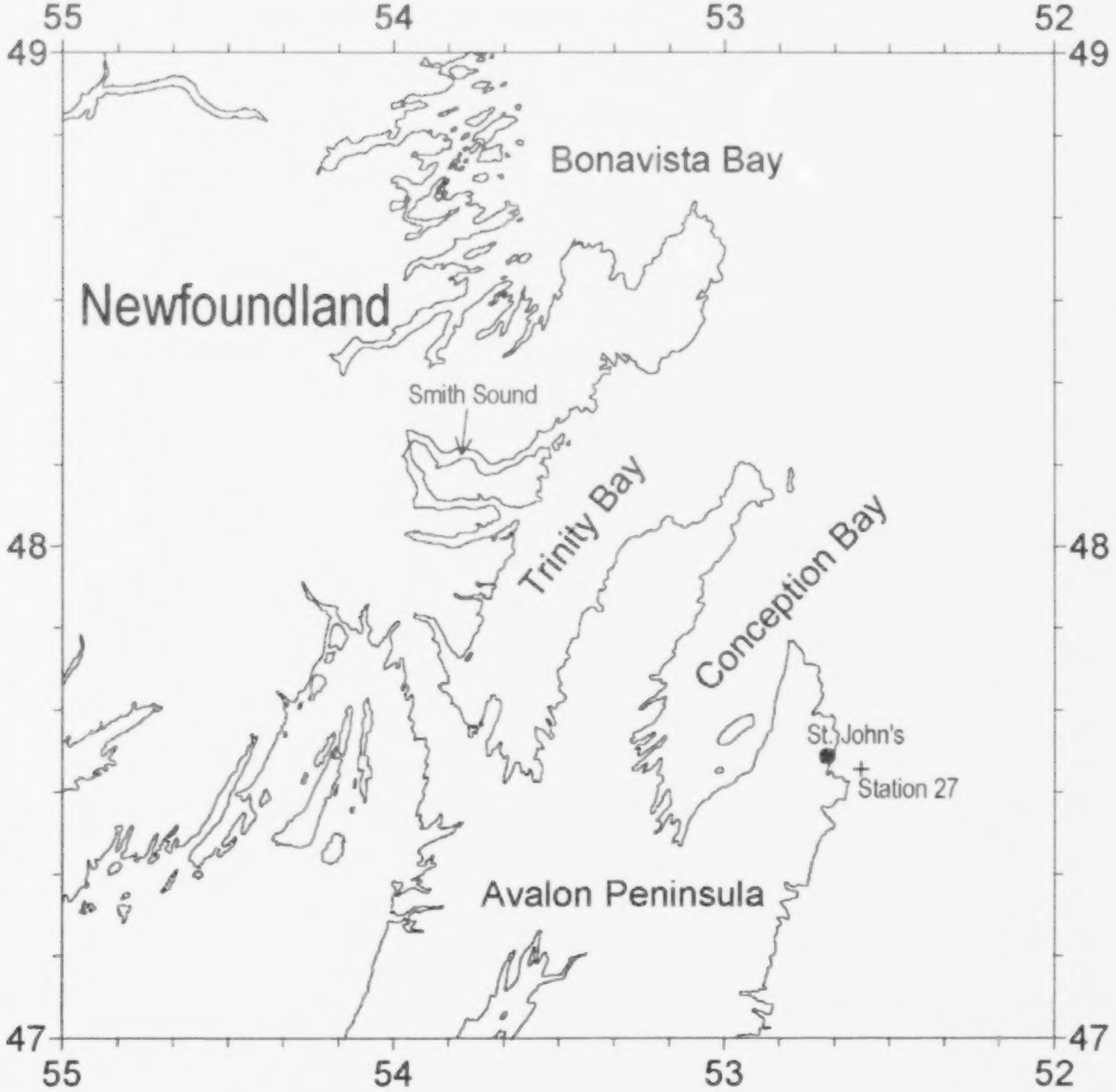
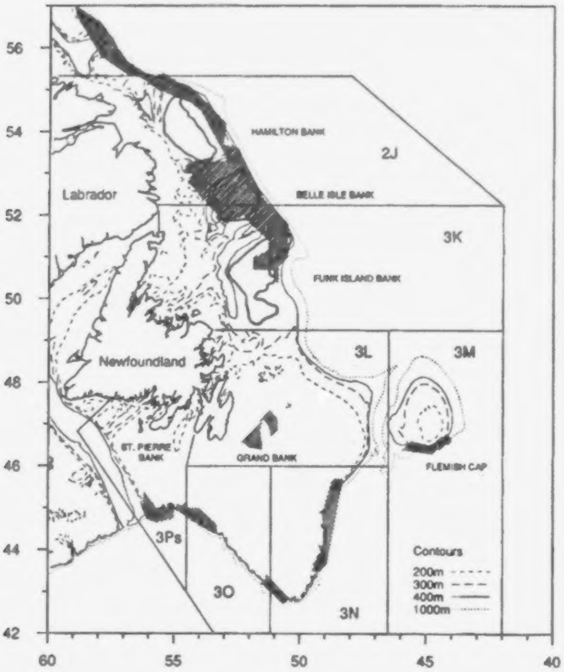
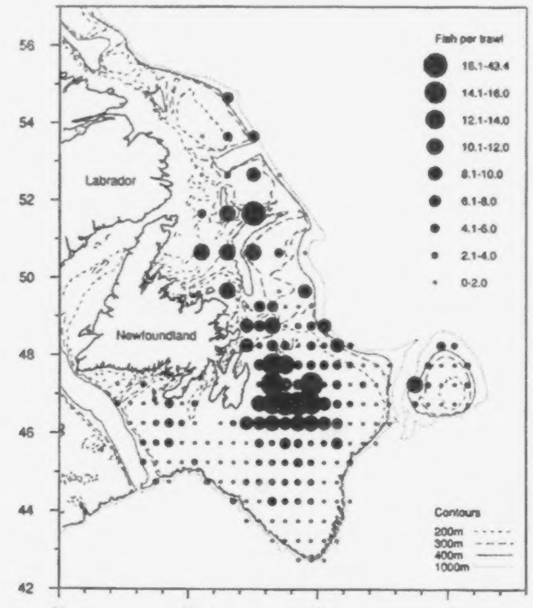

55
54
53
52
49
49
Bonavista Bay
Newfoundland
Smith Sound
Trinity Bay
Conception Bay
48
48
St. John's
Station 27
Avalon Peninsula
47
47
55
54
53
52

Fig. 4. Map of the east coast of Newfoundland, indicating the location of Smith Sound within Trinity Bay and oceanographic Station 27 off St. John's.



56
54
52
50
48
46
44
42
60
55
50
45
40
HAMILTON BANK
2J
Labrador
BELLE ISLE BANK
3K
FUNK ISLAND BANK
3L
3M
Newfoundland
ST. PIERRE BANK
GRAND BANK
FLEMISH CAP
3Ps
3O
3N
Contours
200m
300m
400m
1000m

Fig. 5. Cod in Div. 2J3KL. Spawning locations identified in the review by Fitzpatrick and Miller (1979). This illustration is from Hutchings et al. (1993), who combined the information that Fitzpatrick and Miller (1979) had presented by month (March-July).



Fish per trawl
16.1-43.4
14.1-16.0
12.1-14.0
10.1-12.0
8.1-10.0
6.1-8.0
4.1-6.0
2.1-4.0
0-2.0
56
54
52
50
48
46
44
42
60
55
50
45
Labrador
Newfoundland
Contours
200m
300m
400m
1000m

Fig. 6. Cod in Div. 2J3KL. Relative abundance of fish in spawning condition, as determined from sampling of catches during bottom-trawl surveys. (from Hutchings et al. (1993))

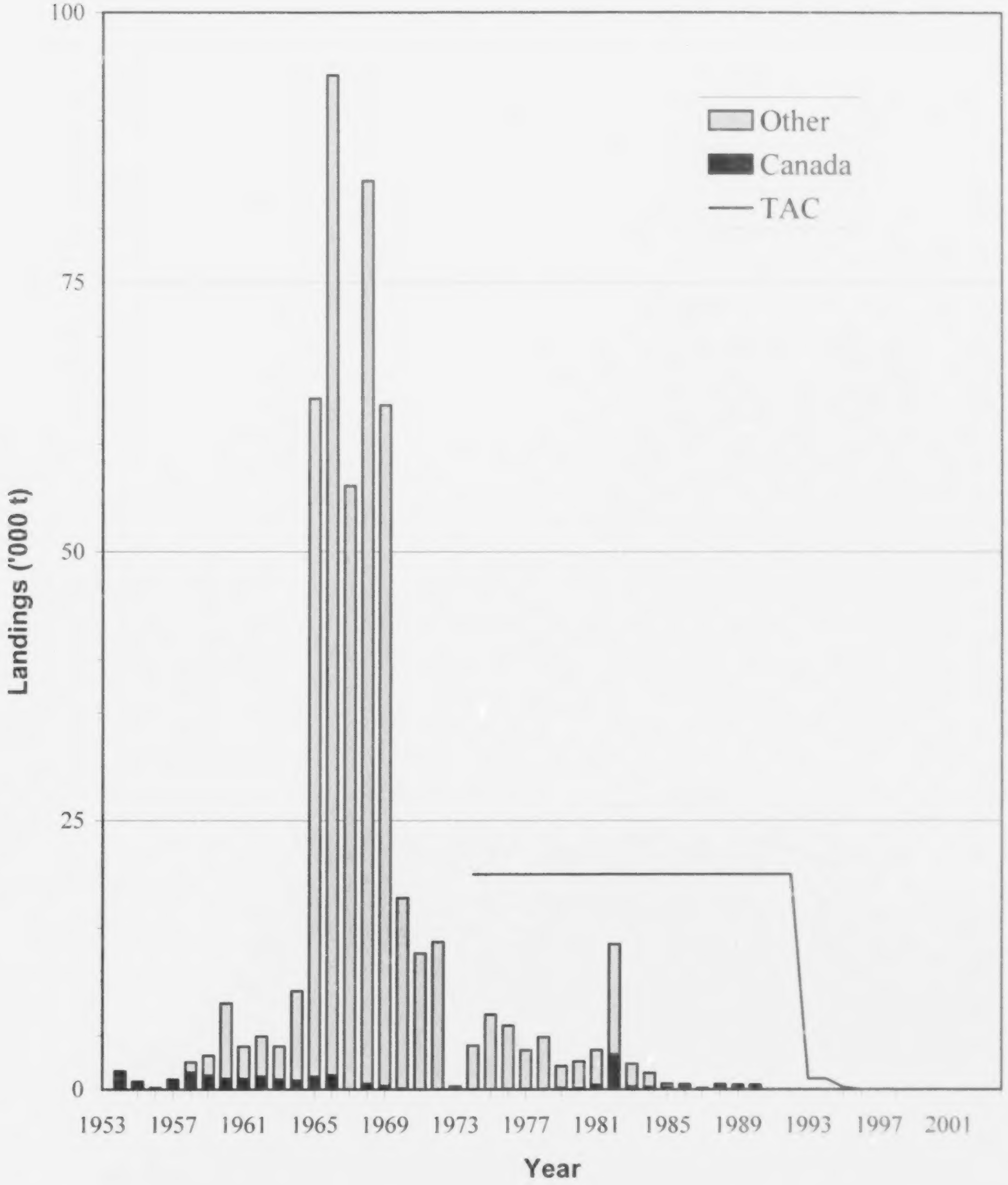


Fig. 7. Cod in Div. 2GH. Total allowable catches (TACs) and landings (thousands of tons) by non-Canadian fleets and Canadian fleets. (data updated from Murphy and Bishop (1995))

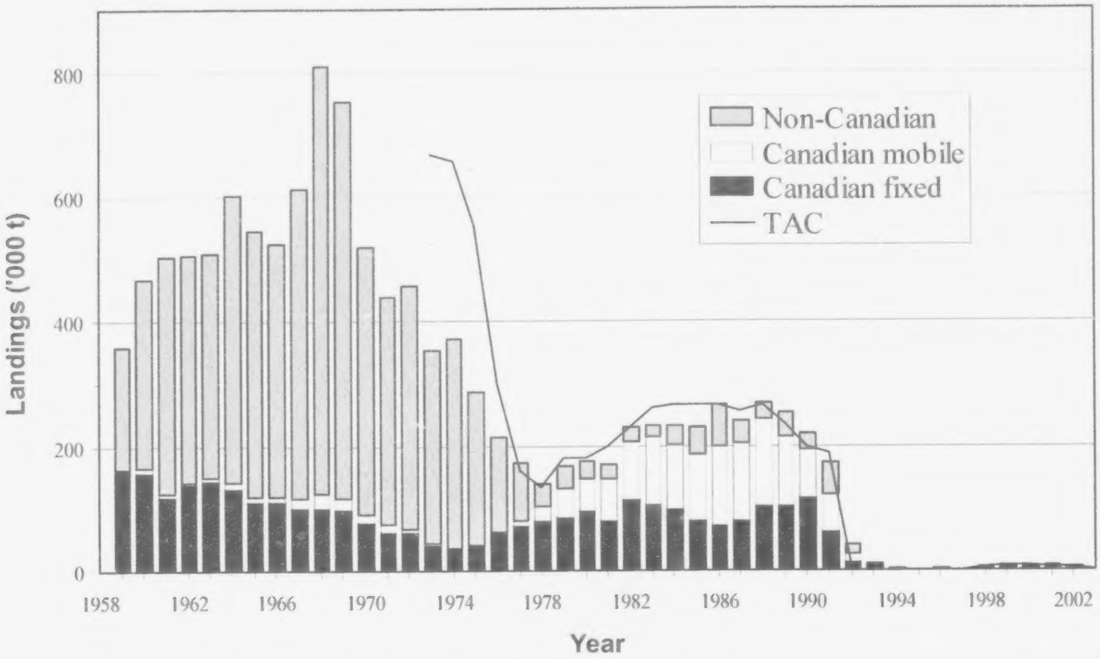


Fig. 8. Cod in Div. 2J3KL. Total allowable catches (TACs) and landings (thousands of tons) by non-Canadian fleets and Canadian fleets, with the latter divided into mobile gear (offshore) and fixed gear (mainly inshore). (modified from Lilly et al. (2003))

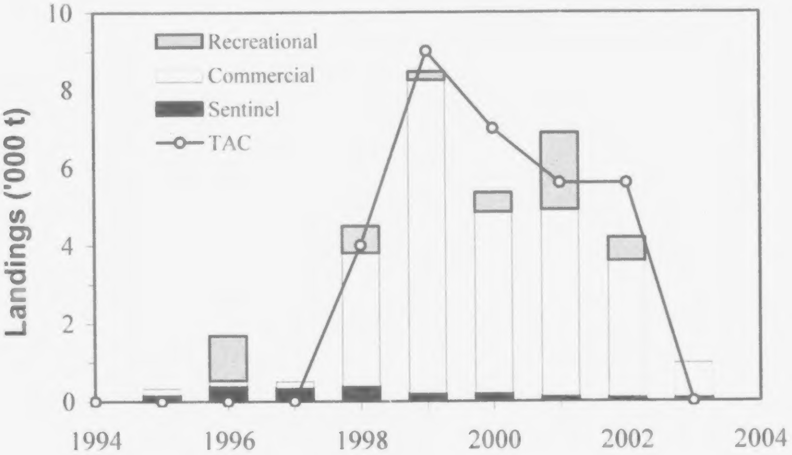


Fig. 9. Cod in Div. 2J3KL. Total allowable catches (TACs) and inshore fixed-gear landings (thousands of tons) for the inshore fishery (1995-2003). The landings are subdivided into sentinel, index/commercial (including by-catch) and food/recreational. Most of the landings in 2003 came from a mass mortality of cod in Smith Sound, Trinity Bay in April. (from Lilly et al. (2003) and DFO (2004a))

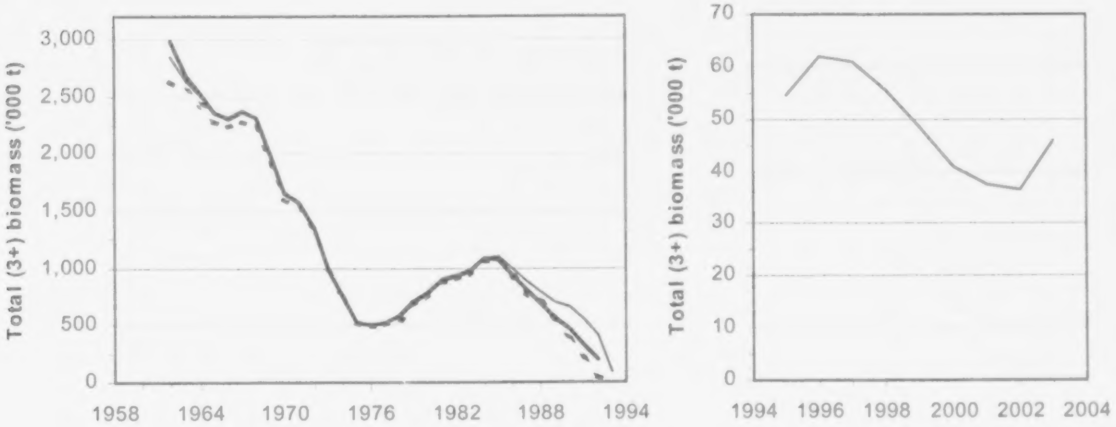


Fig. 10. Trend in total (3+) biomass (thousands of tons) of 2J3KL cod as estimated by sequential population analyses (SPA). In the left panel, the solid bold line shows the biomass from the 1993 assessment (Bishop et al. 1993, reconstructed by P. Shelton), the dashed line shows an "illustrative" model with no alteration of catch (Lilly et al. 1998b) and the thin solid line shows an "illustrative" model with sufficient unreported catch added to allow the model to fit the pattern in the survey index (Smedbol et al. 2002). The right panel shows biomass of fish from an SPA based on catches and indices from the inshore only (Lilly et al. 2003).

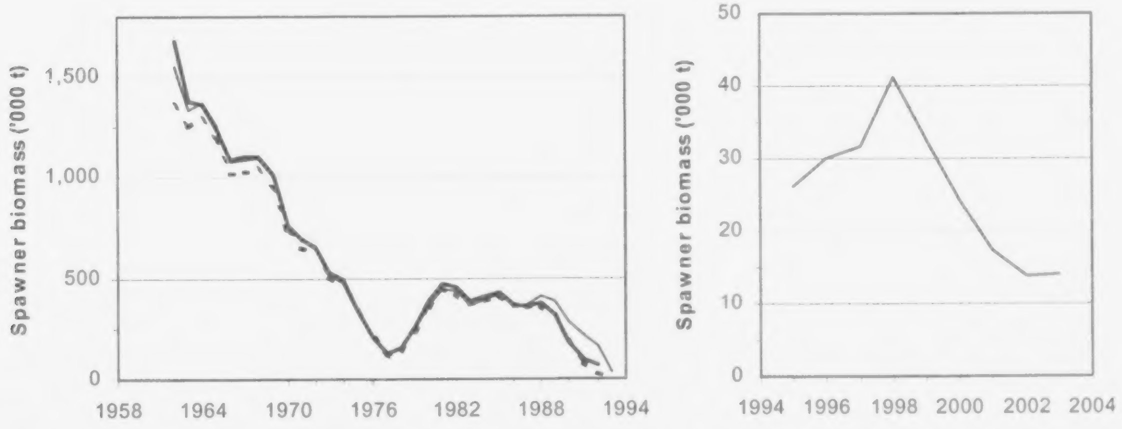


Fig. 11. Trend in spawner stock biomass (SSB, thousands of tons) of 2J3KL cod as estimated by sequential population analyses. Lines as in Figure 10.

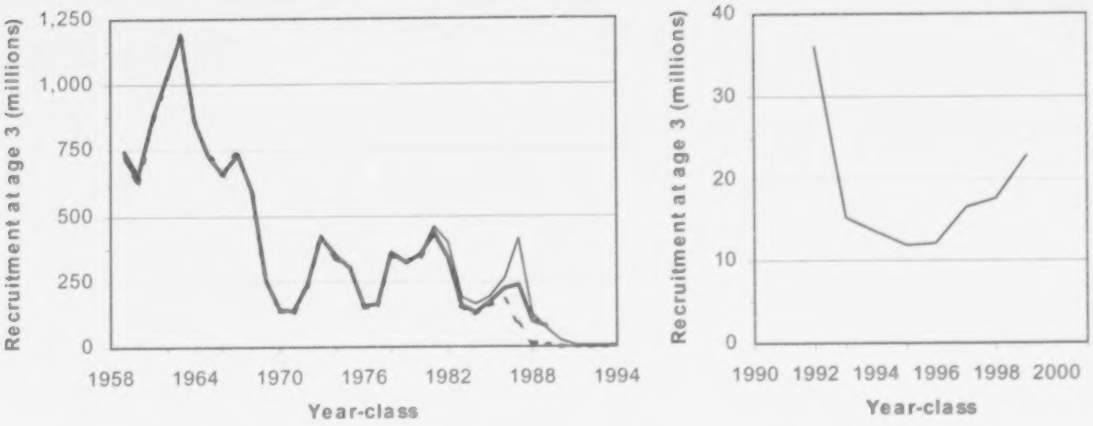


Figure 12. Recruitment at age 3 (in millions) of 2J3KL cod. Lines as in Figure 10.

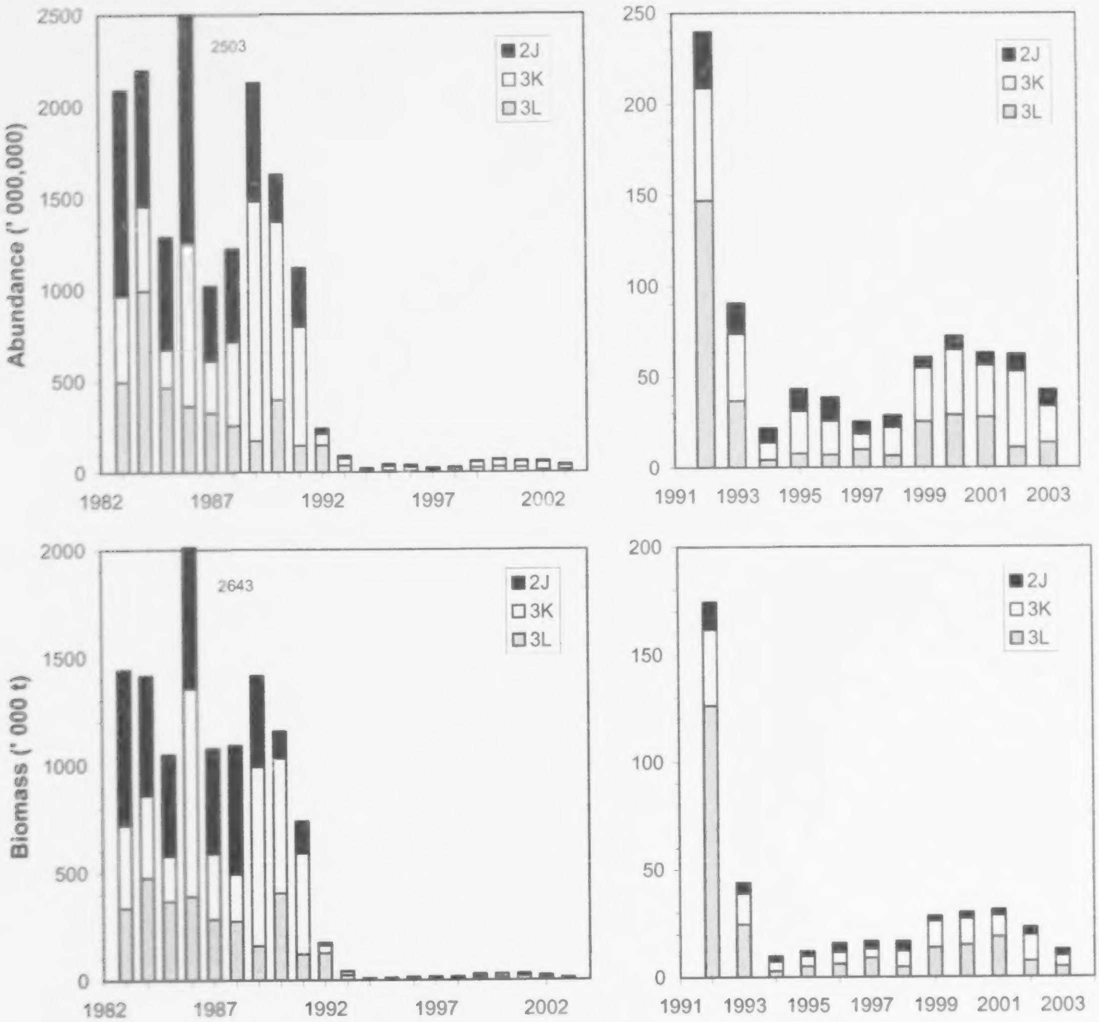


Figure 13. Trend in the index of population abundance (above) and biomass (below) computed by areal expansion of the stratified arithmetic mean catch per tow during autumn bottom-trawl surveys in 2J3KL. The scales on the right panels illustrate just the lower 10% of the left panels, in order that data from 1992-2003 may be discerned. Note that the survey trawl was changed in 1995, and data collected prior to 1995 have been converted so as to be equivalent to data collected from 1995 onward. (from Lilly et al. (2003))

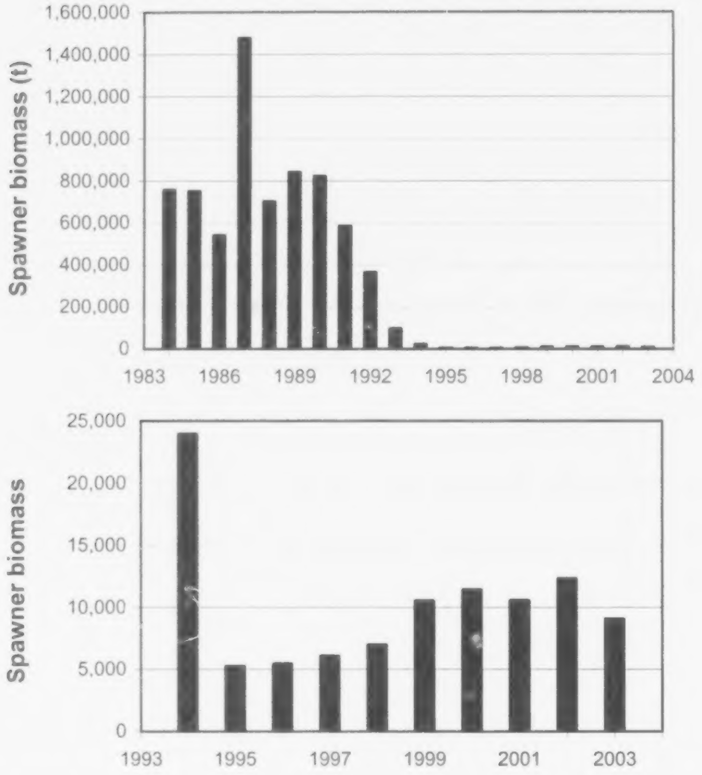


Fig. 14. Trend in the index of spawner stock biomass (SSB) in the offshore of 2J3KL computed by areal expansion of the stratified mean catch at age per tow during autumn bottom-trawl surveys. The catch in autumn of year t has been used to compute biomass on Jan. 1 of year t+1. Note that the survey trawl was changed in 1995, and data collected prior to 1995 have been converted so as to be equivalent to data collected from 1995 onward. (from Lilly et al. (2003))

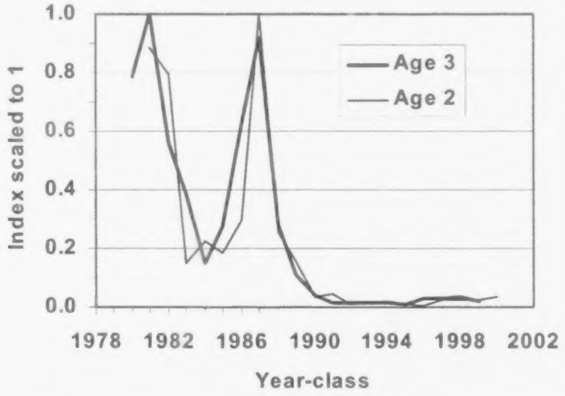


Fig. 15. Relative size of the 1980-1999 year-classes in the offshore of 2J3KL, as measured by the mean catch per tow at ages 2 and 3 during the autumn bottom-trawl surveys. Number per tow has been scaled to a maximum of 1 within the time-series for each age. Note that the survey trawl was changed in 1995, and data collected prior to 1995 have been converted so as to be equivalent to data collected from 1995 onward. (data from Lilly et al. (2003))

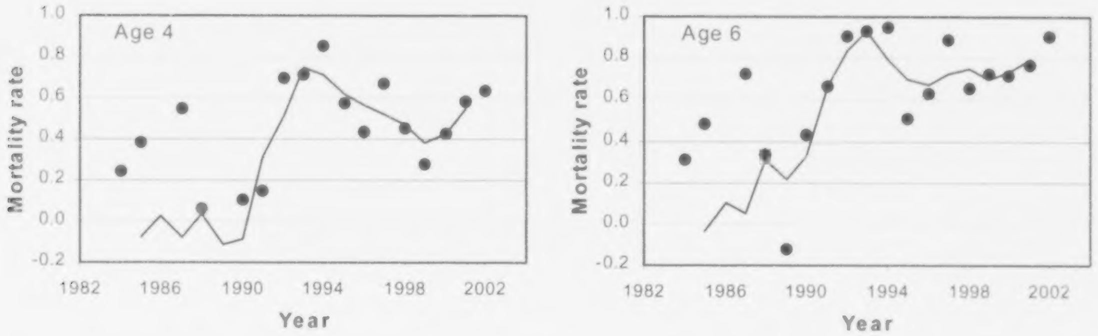


Fig. 16. Age specific mortality in the offshore of 2J3KL as calculated from mean catch per tow at age during the autumn bottom-trawl surveys (from DFO (2003)). As an example, in the age 4 panel, the value of 0.85 in 1994 is the mortality experienced by the 1990 year-class from age 3 in 1993 to age 4 in 1994. The line is a 3-year moving average. Data points less than –0.2, which occurred only before 1990, are not shown. Note that the high level of variability, especially prior to the stock collapse, is a reflection of the high among-year variability in the surveys. The most extreme instance was the anomalously high index value in 1986, which resulted in the appearance of production of fish (negative mortality) from 1985 to 1986 and very high mortality from 1986 to 1987. Note as well that the rates should be interpreted as indicators of trends over time, rather than absolute values. Rates calculated for younger ages (e.g. from age 3 to age 4) may underestimate mortality for two reasons: the proportion of a year-class available to the survey increases with age as the fish move to the offshore from inshore nursery grounds, and the proportion of the fish in the path of the trawl that are actually caught increases with fish length. The latter phenomenon was especially true for the trawl that was used prior to 1995. Although the catch rates from that trawl have been adjusted to those of the new trawl with a length-based conversion formula, the success of the conversion may have declined with decreasing fish length because of an increase in the proportion of sets where some fish of specified length were in the path of the trawl but none were caught.

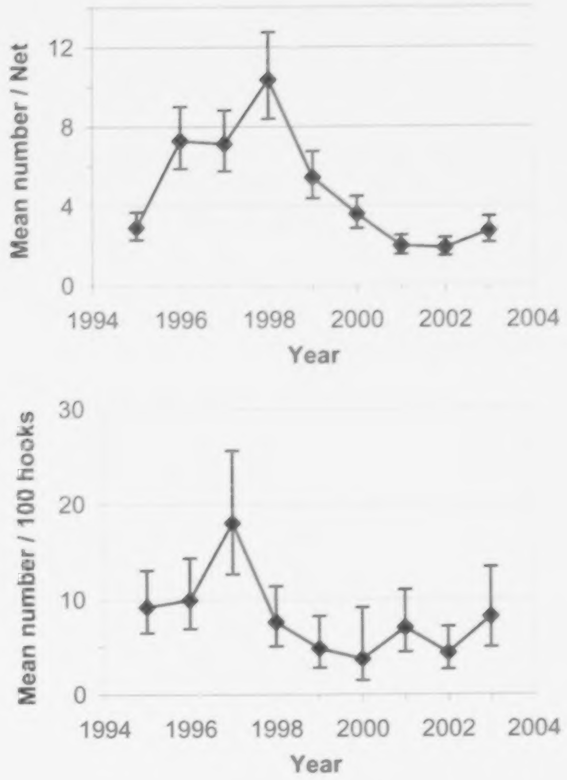


Fig. 17. Standardized catch rates from sentinel surveys in 3KL; gillnets above and linetrawls below. (from DFO (2004a))

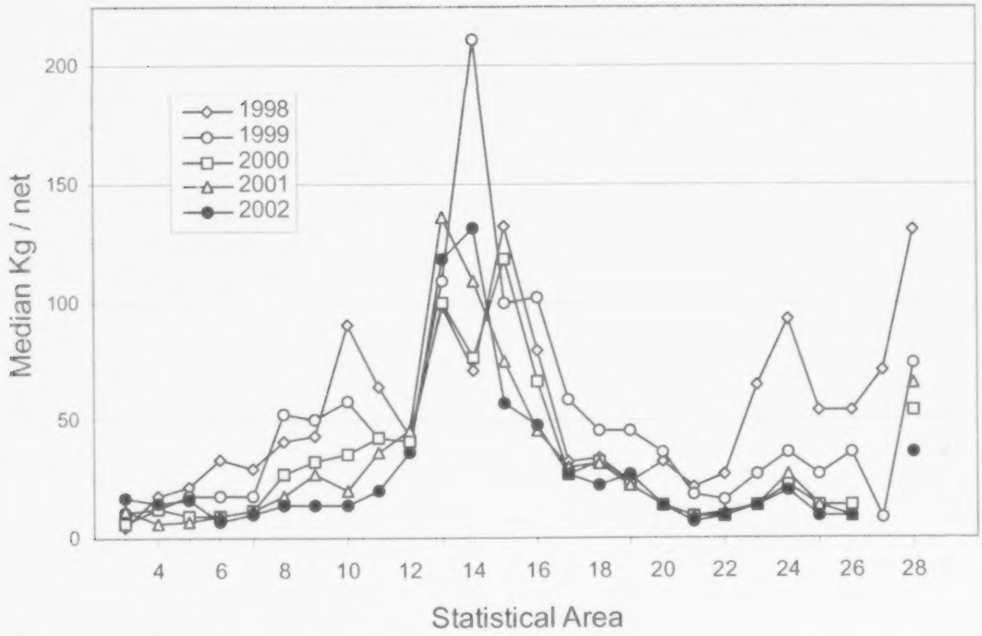


Fig. 18. Median catch rates by statistical section from the gillnet fisheries for cod by vessels <35 feet in length during the 1998-2002 index/commercial fisheries. From north to south, area 2 starts at Cape Bauld, 6 at Cape St. John, 10 at Cape Freels, 14 at Cape Bonavista, 20 at Grates Point, 24 at Cape St. Francis and 27 at Cape Race. (from Lilly et al. (2003))

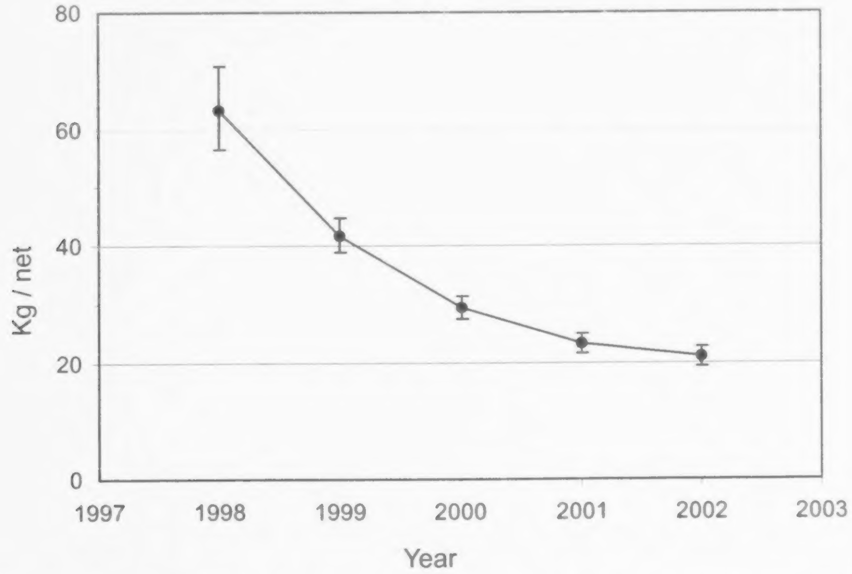


Fig. 19. Standardized catch rates from the gillnet fisheries for cod by vessels <35 feet in length in 3KL combined during the 1998-2002 index/commercial fisheries. (from Lilly et al. (2003))

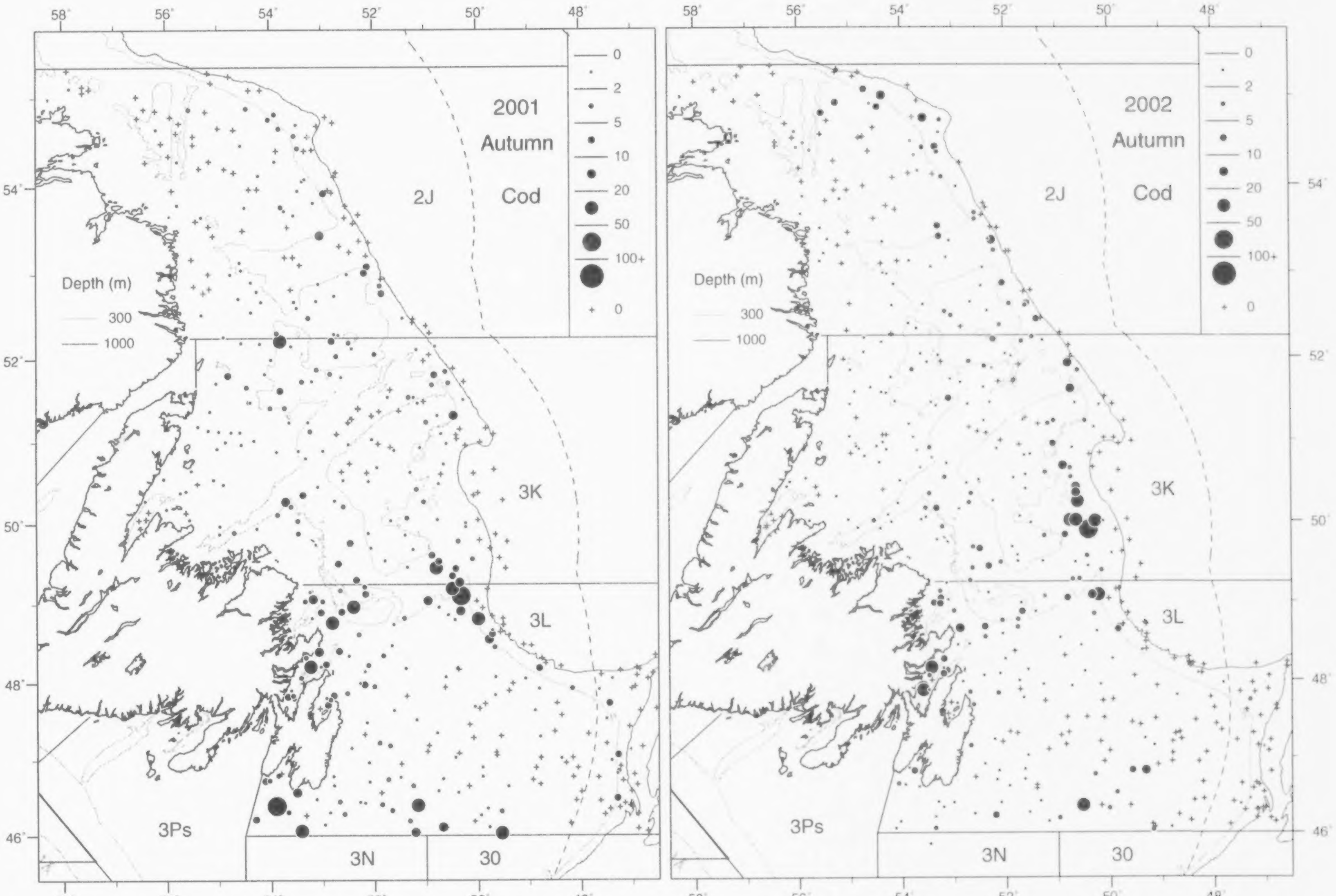

2001
Autumn
Cod
2002
Autumn
Cod
0
2
5
10
20
50
100+
0
Depth (m)
300
1000
2J
3K
3L
3N
3O
3Ps
58°
56°
54°
52°
50°
48°
46°

Fig. 20. Cod distribution (kg per standard tow) during the autumn surveys in divisions 2J3KL in 2001 and 2002.

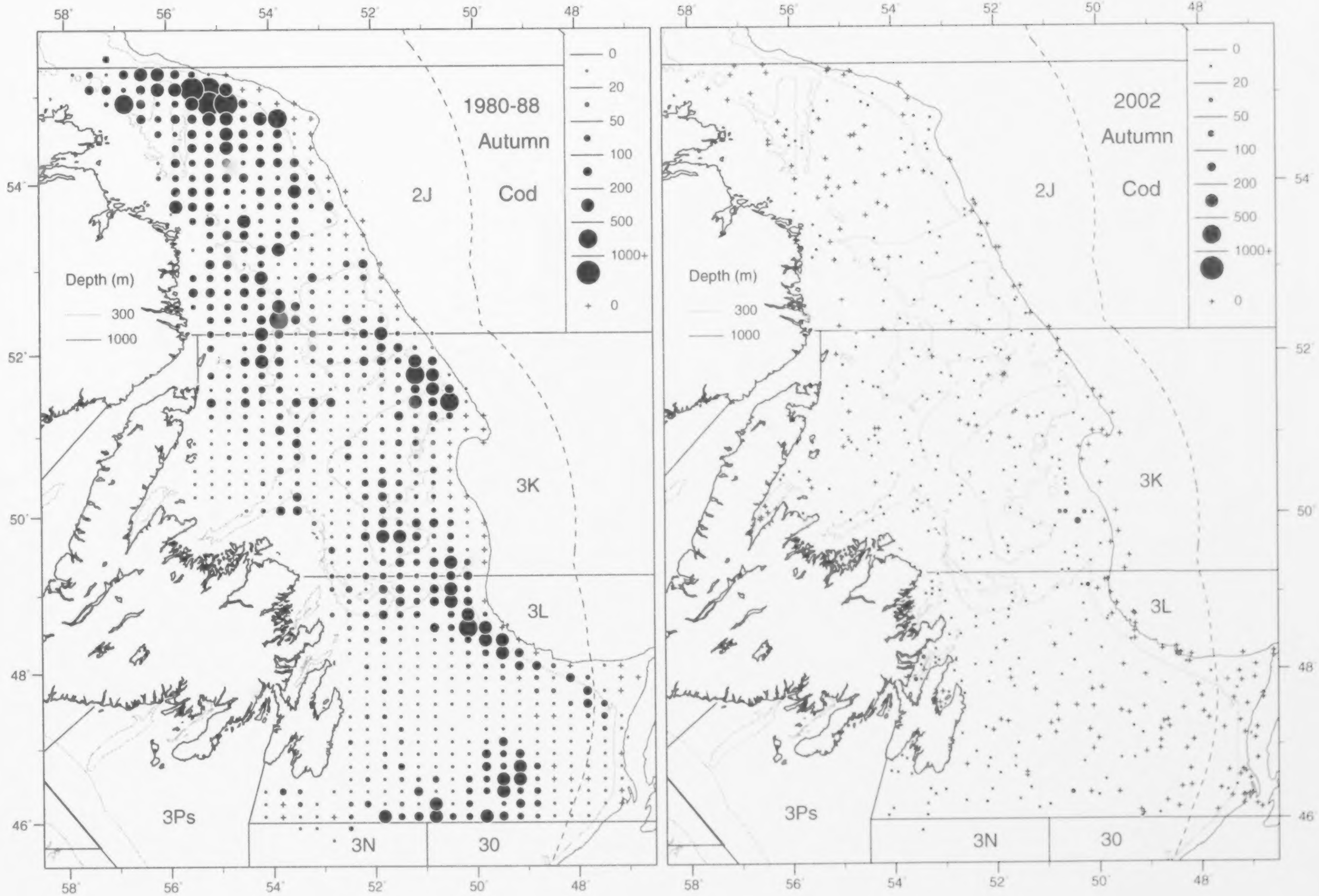
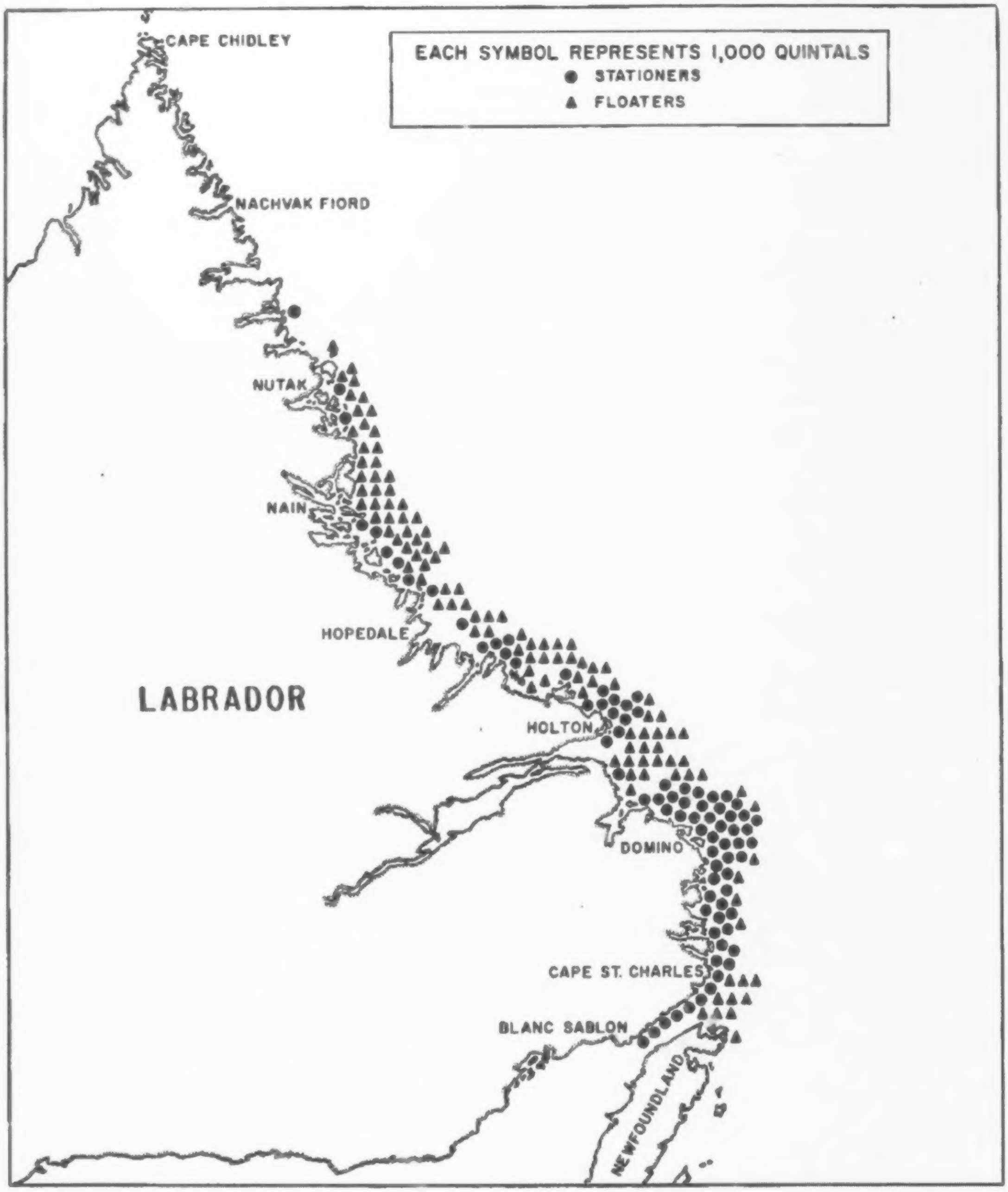

1980-88
Autumn
Cod
2J
3K
3L
3N
30
3Ps
Depth (m)
300
1000
0
20
50
100
200
500
1000+
0
2002
Autumn
Cod
58°
56°
54°
52°
50°
48°
46°

Fig. 21. Cod distribution (kg per standard tow) during the autumn surveys in divisions 2J3KL. The left panel (from Lilly 1994) illustrates the average catch per 30 min tow with the Engels trawl within areas of 10' latitude amd 20' longitude. All tows during 1980-1988 were combined. The right panel shows the catches per 15 min tow with the Campelen trawl during 2002. Data are as in Fig. 20, but note change in scale.



CAPE CHIDLEY
EACH SYMBOL REPRESENTS 1,000 QUINTALS
● STATIONERS
▲ FLOATERS
NACHVAK FIORD
NUTAK
NAIN
HOPEDALE
LABRADOR
HOLTON
DOMINO
CAPE ST. CHARLES
BLANC SABLON
NEWFOUNDLAND

Fig. 22a. Locations of capture of inshore cod in Labrador by stationers (shore-based fish harvesters) and floaters (schooner-based fish harvesters) in 1949. 1000 quintals of heavily salted, dried cod, equals about 420,000 pounds of round fresh cod. (from Templeman (1966))

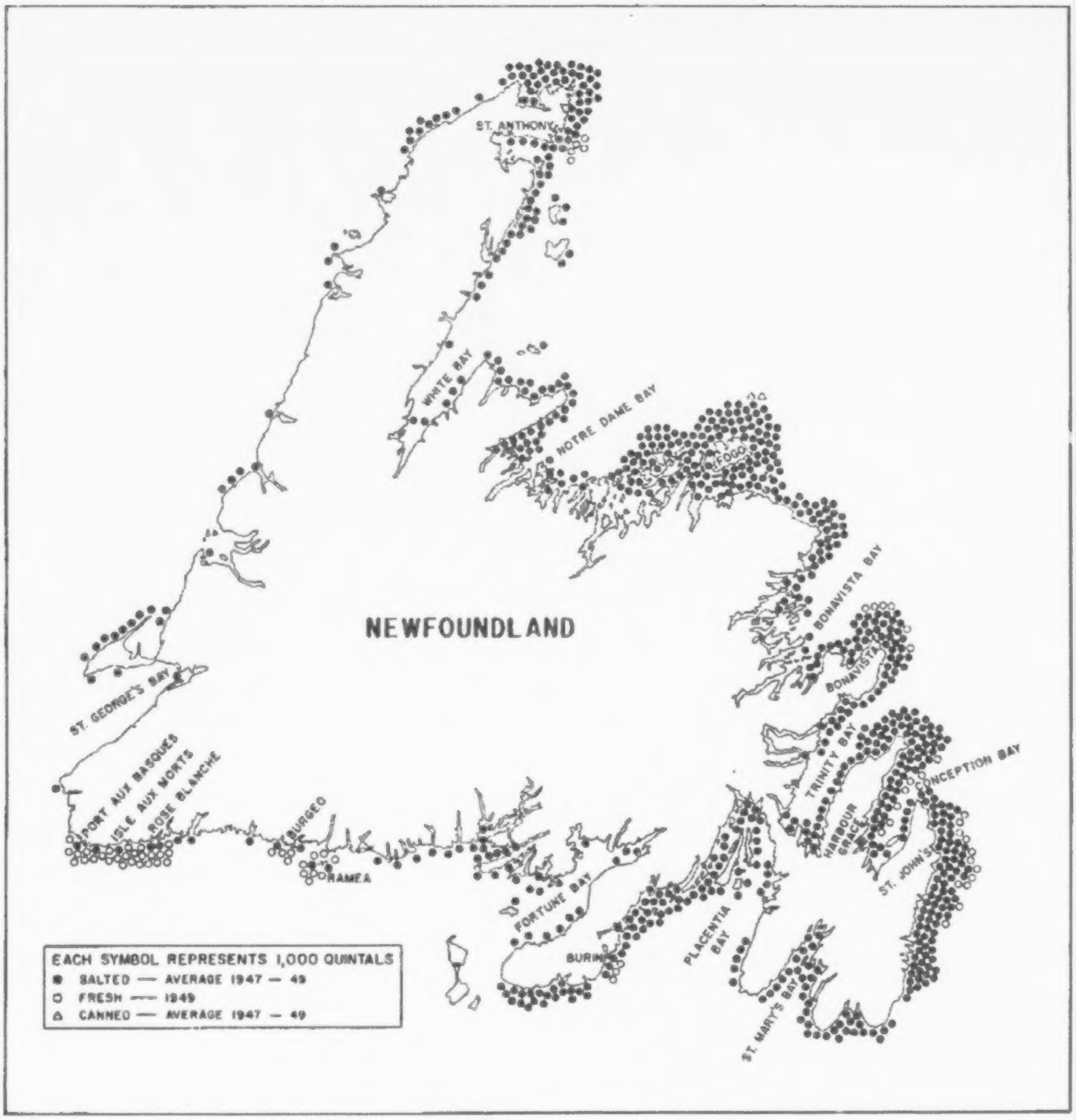

ST. ANTHONY
WHITE BAY
NOTRE DAME BAY
FOGO
NEWFOUNDLAND
BONAVISTA BAY
BONAVISTA
TRINITY BAY
CONCEPTION BAY
HARBOUR GRACE
ST. JOHN'S
ST. GEORGE'S BAY
PORT AUX BASQUES
ISLE AUX MORTS
ROSE BLANCHE
BURGEO
RAMEA
FORTUNE BAY
BURIN
PLACENTIA BAY
ST. MARY'S BAY
EACH SYMBOL REPRESENTS 1,000 QUINTALS
● SALTED — AVERAGE 1947 — 49
○ FRESH — 1949
△ CANNED — AVERAGE 1947 — 49

Fig. 22b. Locations of capture (average yearly landings) of inshore cod in Newfoundland in 1947-1949. 1000 quintals of mainly lightly salted, dried cod, equals about 500,000 pounds of round fresh cod. (from Templeman (1966))

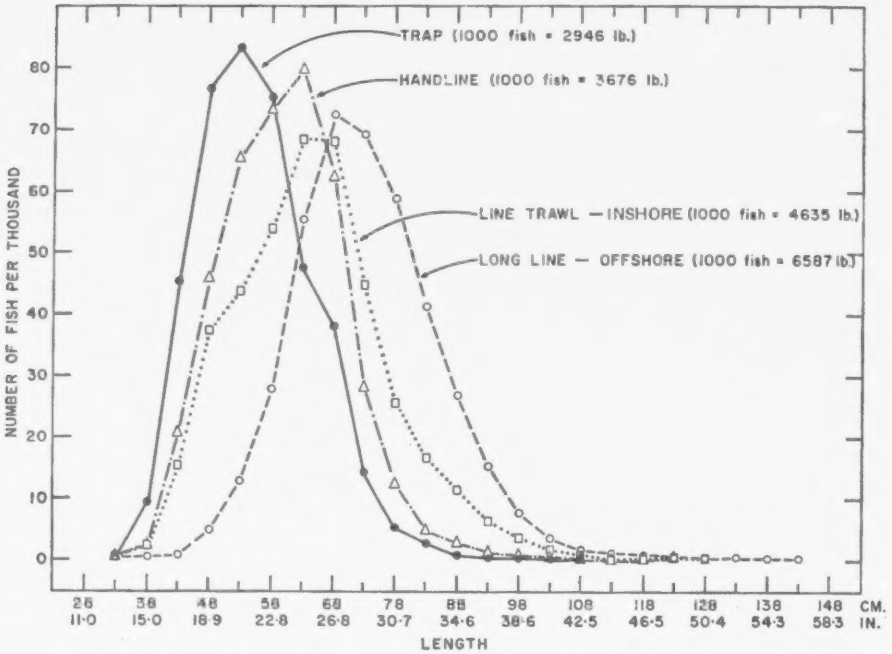


Fig. 23. Number of cod at each length interval per thousand total, from trap, handline, inshore trawl, and offshore longline, at Bonavista, 1950-1953. The weights per thousand fish shown in the body of the figure are of gutted and gilled fish. (from Templeman and Fleming (1956))

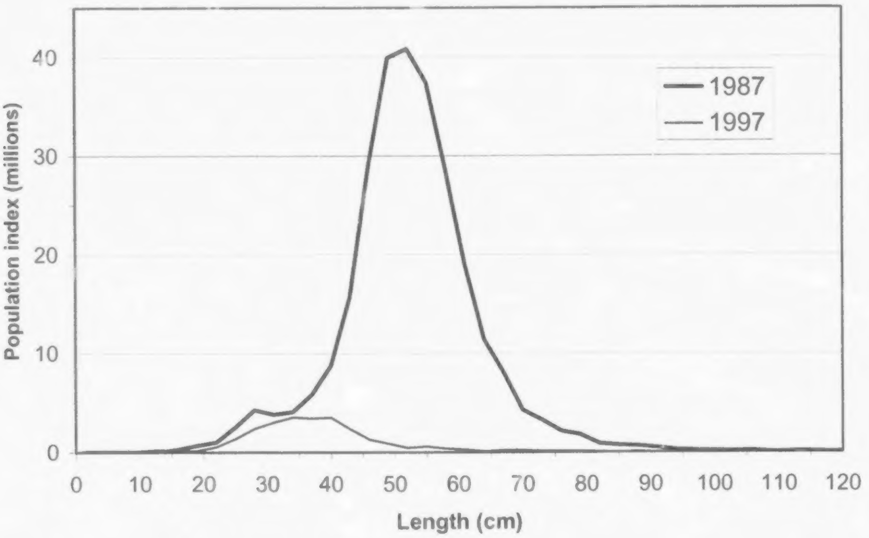


Fig. 24. Index of number of cod at length (3-cm length-groups) in 2J3KL in 1987 and 1997, as estimated by areal expansion of the arithmetic mean catch at length per tow during DFO research bottom-trawl surveys. The catch numbers at length from 1987 have not been adjusted so as to be equivalent to catches that would have been obtained had the Campelen trawl been used. The conversion would add many fish to the shorter lengths.

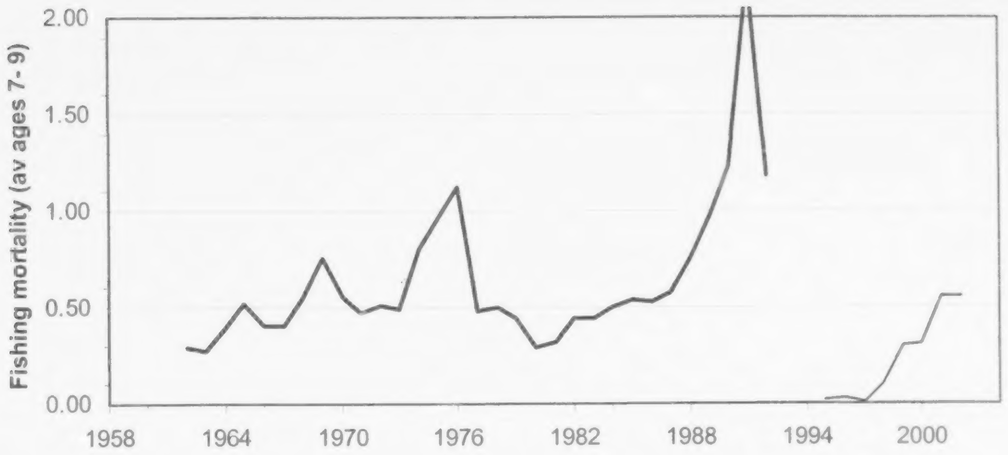


Fig. 25. Fishing mortality, averaged over ages 7-9, in the 2J3KL cod stock. The heavy line is from the whole stock SPA from the 1993 assessment (Bishop et al. 1993) and the light line is from the inshore SPA (Lilly et al. (2003)).

Appendix 1. The inshore cod of Div. 3K and 3L.

[Much of the following information is extracted directly from Lilly et al. (1999), with some sections updated from Lilly et al. (2003).]

The inshore region of Div. 3KL has gained a greatly increased degree of prominence in the assessment of 2J3KL cod since the mid-1990s. By the autumn of 1994 there appeared to be very few cod left within the boundaries of the 2J3KL stock complex. In spring 1995, a research vessel unexpectedly found a dense aggregation of cod in Smith Sound, Trinity Bay, and during summer/autumn of 1995 participants in the new sentinel survey program experienced good catch rates of commercial size cod over much of the area from central 3K to southern 3L. In 1998 a TAC was reintroduced to the inshore for vessels less than 65 feet in length, and this fishery continued through 2002.

Information on the general biology (e.g. distribution, spawning, feeding, growth, condition) of cod in the inshore may be found in Lilly et al. (1998a) and Lilly et al. (1999), and in the many sources cited therein. Our knowledge of the biology of cod in the inshore has increased rapidly through interviews with fishermen (e.g. Neis et al. 1999; Hutchings and Ferguson 2000; Jarvis and Stead 2001) and an intensification of study, including a tagging program, sentinel surveys, a logbook program for commercial vessels under 35 feet in length, acoustic surveys in specific areas, and an extension of the autumn survey into new strata in the inshore.

A1.1 Definitions of inshore and offshore

The terms "inshore" and "offshore" have created some confusion within assessment meetings in the past. There was a request during the 1998 cod zonal assessment meeting for clear and unambiguous definitions. This may not be possible. It is recognized that a cod trap set within a few metres of land is in the inshore and a trawler fishing on the outer edge of Funk Island Bank is in the offshore. However, there is no distinct dividing line between the two. For example, a 55 foot vessel might set gillnets at various depths and at various distances from shore, such as follows: at a depth of 40 m close to shore adjacent to gillnets set by a 30 foot vessel, at 250-300 m some 25 nautical miles northeast of Cape Bonavista, or at 40 m on the plateau of Grand Bank near grounds fished by large otter trawlers. Which of these fishing operations are inshore and which are offshore?

For many years it was the custom within the documentation of the 2J3KL assessment to refer to all landings from fixed gear (traps, gillnets, and various types of hook and line) as inshore and landings from mobile gear (otter trawls) as offshore. The terms were also used in quota allocation, whereby there was for many years a quota for the stock as a whole, but the "inshore" was given an allocation which it was permitted to overrun. In this context, only vessels less than 65 feet in length were considered to be part of the inshore fleet. (It may be noted that in some contexts there is additional classification by vessel size, so that one may see vessels less than 35 feet referred to as "inshore", vessels 35-65 feet as "nearshore" and vessels 65-100 feet as middle distance.) The definition by gear type would not be a problem if fixed gears were deployed only close to the coast. However, longliners had been introduced to eastern Newfoundland waters in the early 1950s to exploit the aggregations of cod found in the deep water off the headlands, such as off Cape Bonavista. In these waters they overlapped the fishing areas of distant-water trawler fleets. Definition by gear type became much more problematical in the mid-1980s as the longliner fleet (which became predominantly a gillnet fleet in the 1960s) started to move further offshore, especially onto the plateau of Grand Bank. The inshore component was then clearly overlapping areas that had been fished with otter trawls for decades, and some of the catch in the inshore allocation was actually coming from far offshore. (It is worth recalling that, in an historical context, the plateau of Grand Bank was fished with longlines for centuries, and dory vessels continued to fish the plateau of the bank into the 1960s.)

The terms inshore and offshore have recently been used with respect to the geographic coverage by the research trawl surveys. When the stratification scheme was established, it was decided that the strata would not include the 12-mile coastal zone (Doubleday 1981; p. 24). Starting in the autumn of 1996, new strata were established closer to shore and within the bays of Divisions 3K and 3L. These new strata have been referred to as being inshore, to distinguish them from the older strata that are referred to as offshore. However, it appears that these strata do not extend into the shallow, very near-shore coastal area in which most of the sentinel surveying has been conducted since 1995, and in which most of the commercial fishing was conducted in 1998-2002.

Thus, there is no correspondence between the inshore as defined for allocating quota, inshore as sometimes employed in assessments for aggregating the fixed gear catch, and inshore as used in discussing the research surveys. The terms "inshore" and "offshore" are widely used within the fishing industry and are convenient terms of geographic reference in general discussion, but at present their usage is not consistent among all contexts.

A1.2 Observations of cod in the inshore

Cod in Divisions 2J3KL historically migrated on a seasonal basis between a summer-autumn feeding area in shallow water along the coast of southern Labrador and eastern Newfoundland and an overwintering area offshore, primarily near the shelf break. However, not all cod moved offshore in the winter. Some remained near the coastal shelves in deep water below the Cold Intermediate Layer (CIL) of the Labrador Current, and some remained within the bays of eastern Newfoundland, often in narrow fjord-like environments. In recent years the quantity of cod caught during autumn research bottom-trawl surveys in offshore waters has been very low, but there have been numerous reports of cod in shallow coastal waters, catch rates have been good to excellent in sentinel surveys from White Bay south, and dense aggregations of cod have been found and studied in deep inlets in the inner reaches of Trinity Bay.

A1.2.1 Linking the inshore to the offshore

Several studies in the 1960s demonstrated a close association between the cod caught in inshore waters and the cod caught on the outer shelf. The most compelling information was the pattern of returns from tagging studies in both the offshore and the inshore in the early to mid-1960s (Postolakii 1966; Templeman 1974) but there were also analyses of catch rates, fish size and growth rate. Fleming (1965), Hodder (1965) and May (1967) showed that the catch per fisher in the inshore declined as catches by distant-water fleets increased in the offshore in the late 1950s and early 1960s. Referring to sampling during 1955-1962, Hodder (1965) concluded: "The decreased abundance of fish older than 6 years in the inshore trap fishery is attributed to the decreased abundance of these older ages on the offshore fishing grounds as a result of increased effort by trawlers in all areas off the east coast of Newfoundland and southern Labrador in recent years." May et al. (1965) used random samples of research vessel trawl catches and catches by various gears in the inshore commercial fishery in 1960-1962 to calculate mean length-at-age of cod in ICNAF Divisions from 2H to 3Pn. They found that von Bertalanffy growth curves "... derived from the offshore data provide an adequate representation of the inshore material as well, lending evidence to the hypothesis that there is no inshore-offshore stock separation in the areas concerned." It should be noted, however, that the inshore samples came from communities on headlands and exposed coasts, and may have been dominated by migrating fish.

A1.2.2 Cod in deep waters off headlands

The presence of cod in deep water off the coastal shelves of eastern Newfoundland has been recognised since exploratory longlining in the early 1950s (Templeman and Fleming 1956, 1963). Not all the cod in these areas, just below the depth at which the Cold Intermediate Layer of the Labrador Current impinges on the bottom, arrived from near the shelf break following spawning. In the 1980s the fishery in the deep water started each spring very soon after the disappearance of the ice, and often long before the sudden increase in landings toward the middle or end of June in adjacent shallow waters (unpubl. data). In addition, research trawling off Cape Bonavista and in the mouth of Trinity Bay has yielded good catches in February-April (Lilly 1982; unpubl. data). Thus, some cod are in this deep-water coastal environment months before the migration of cod from the offshore. Templeman (1962) presented several arguments in support of a suggestion that "... each large shelf region, such as the Bonavista Shelf, the Fogo Shelf and the St. Anthony Shelf, projecting seaward with deep water on each side has a basic stock of its own, some of which it loses temporarily in the summer by coastal or pelagic feeding migrations and in the winter by movements in the deep water, while receiving some migrants from other areas."

As reported by Hutchings et al. (1993), there is evidence of spawning in the deep water off Cape Bonavista. Cod caught in the commercial gillnet fishery northeast of the Cape in 275-350 m were sampled weekly in 1983 and 1984. A plot of a gonad-somatic index versus time illustrates that there were many cod with relatively large gonads when the first samples were collected (May 11 in 1983 and May 30 in 1984), and that the proportion of cod with elevated indices, and the maximum values of the indices, declined to a minimum by the middle or end of July (Lilly 1996). The decline in gonad indices provides only circumstantial evidence that cod spawn in deep water off the Bonavista Shelf. The cod with low gonad indices could have spawned elsewhere before migrating into the area, and cod with large gonads may have moved elsewhere to spawn if they had not been caught.

A1.2.3 Cod in eastern bays

Reports of the presence of cod in spawning condition in the bays of eastern Newfoundland may be found in the scientific literature as early as the 1890s, when Neilsen described how he obtained fish in spawning condition for the Dildo Island Marine Hatchery in May-June in Trinity

Bay. In discussing an early run of cod at the head of Trinity Bay in 1894, Neilsen (1895) was of the opinion that the "... early occurrence of fish seems clearly to indicate that those fish do not enter the bay from the outside, but that they are *local-bred* fish, which keep in deep water during winter, and on the first opportunity in the spring, seek the shoaler waters in the head of the bay ...".

Additional evidence of the presence of spawning cod within eastern bays may be found in unpublished trip reports (Marinus 67-1, 68-1, 68-2) which describe the maturity of cod caught during experimental gillnetting in the deep water of Trinity and Bonavista bays. These data have been summarised by Hutchings et al. (1993). Cod were caught with 6- and 7-inch mesh monofilament gillnets off Tickle Harbour Point and the Horse Chops in Trinity Bay and near Little Denier and Cabot Island in Bonavista Bay in April-June of 1967 and 1968. All gillnet sets were made in deep water with the nets usually running from cold water into the underlying warmer water. In 1967 many of the cod were in spawning condition or close to it (Fleming 1967), and in 1968 the cod were in maturity stages indicating spawning was soon to occur (Fleming 1968). Fleming (1968) thought that the gillnet experiments were sampling "... a segment of the stock which ... consists of large old cod which have escaped other gears, and which spawn in the coastal areas and bays in contrast to the younger fish being caught by traps and handlines which spawn before arriving in the coastal areas in the spring."

It is interesting to note that Templeman (1962) considered his Avalon-Burin stock to be "... an inshore stock ... extending from the outer coast of the Avalon Peninsula into Fortune Bay". In concluding his discussion of the Labrador-Newfoundland stock, he stated: "Very likely in the future enough differences will be found to indicate a number of north-south and inshore-offshore sub-stocks ..." (Templeman 1962). However, Templeman did not present evidence of inshore stocks north of the Avalon Peninsula (other than the coastal shelf "sub-stocks" discussed above), and he did not speak of "bay stocks".

A1.2.4 Cod in fjord-like environments

Cod have for many years been caught through holes cut in the ice in sheltered inlets and embayments of the east and northeast coasts (e.g. Neis et al. 1996). The only such areas that have been studied extensively using scientific techniques are the three fjord-like arms near Random Island on the western side of Trinity Bay.

Most attention in the late 1980s and early 1990s was focused on the two southern arms (Northwest Arm and Southwest Arm) where DFO and especially the Fisheries Oceanography Group at Memorial University of Newfoundland conducted tagging experiments and documented various aspects of the biology of cod that overwintered inshore, including their movements and spawning (Wroblewski, et al. 1994, 1995a; Smedbol and Wroblewski 1997).

The focus shifted to Smith Sound following discovery of a large and dense aggregation of cod in spring 1995 (Rose 1996; Brattey 1997; Morgan and Brattey 1997; Brattey and Porter 1997; Porter et al. 1998; Rose 2003) There is much evidence that cod have always overwintered in this area, but the recent winter/spring aggregations appear to be much larger than people were aware of in the past. There seems to be a general pattern of cod aggregating in the Sound in the winter and moving out sometime in spring, but the timing of these movements is not well understood.

A1.2.5 Cod in the shallow-water fishery

Cod in shallow water along the coast of southern Labrador and eastern Newfoundland supported a fishery with hook and line for centuries. Since the late 19th century this fishery has been strongly augmented by the use of the cod trap, and since the 1960s by the use of synthetic gillnets. The geographic pattern of the catch in 1947-1949 does not support the supposition that "bay stocks" made important contributions to the total inshore catch. Templeman (1958) stated: "Within the east coast area, cod are most abundant near the projecting island and headland areas such as the Cape Bauld - St. Anthony, Fogo Island, Cape Freels, Cape Bonavista, Bay de Verde - Grates Point areas and in the areas to the east of the Avalon Peninsula. ... As a rule far fewer cod are available in the deep inlets and warmer water at the heads of the east coast bays than at the headlands."

In years prior to the collapse, areas of largest catch had in common a closeness to the schools of cod migrating toward the coast from their offshore overwintering areas. If all cod caught in the inshore shallow-water fishery arrived from the offshore, then the earliest landings would be expected at the headlands. However, substantial landings occurred in the inner parts of Bonavista and Trinity Bays several weeks prior to the big increase in landings at the tips of the headlands. See Lilly (1996) for some preliminary analyses of these patterns based on purchase slips. These patterns appear to correspond to the descriptions of herring fish and capelin fish as reported by fishers (Alverson et al. 1987, p. 28-29; Neis et al. 1996). Additional research is required to determine if the early landings (prior to about mid-June) in the inner parts of Bonavista Bay and Trinity Bay were supported by cod which remained within the bays throughout the winter and the later landings were supported by cod which migrated into the coastal areas from farther offshore.

It is tempting to speculate that cod taken in the early landings belong to "bay stocks". It would be of interest to determine if cod taken in the early landings differed from cod taken from later landings with respect to length-at-age, relative year-class strength, otolith structure, and other biological characteristics Unfortunately, the data required to conduct these analyses may not have been collected prior to the 1990's. Most routine sampling of inshore catch was conducted on the outer shores and headlands after mid-June. The early catch in the inner parts of the bays may have been rarely sampled.

A1.2.6 Recent observations of cod in shallow water

A surprising aspect of the cod currently in coastal waters is the large number of reports of cod being seen near the surface and cod being caught in shallow-water gear, including gillnets set for herring, lumpfish and winter (blackback) flounder. Cod have even been caught in lobster pots. Such reports were common in the mid-1990s (Neis et al. 1996; Davis 1996; numerous personal communications to scientists; communications in public media, such as the Evening Telegram, St. John's, NL, 25 May 1996, p.4) and are commonly heard today.

Reports of cod in shallow water became frequent in the winters of 1997-1998 and 1998-1999. These reports came primarily from two areas: Notre Dame Bay on the northeast coast and southwestern Bonavista Bay on the east coast. Reports from Notre Dame Bay included the following. On December 30-31, 1997, cod up to 3 feet (91 cm) in length were reported frozen in ice at Baytona, a community in the inner reaches of the bay. Observers noted the presence of smelt in the area. On January 6-7, 1998, cod were seen in ice near the Twillingate Causeway, which is further out in the bay. Harp seals were reported in the area. From January 11 to approximately January 16, 1999, cod were found dead and dying in and below ice in Virgin Arm, again in the outer part of the bay. It was estimated by Fishery Officers, who interviewed divers and other people who harvested the fish, that perhaps 200,000 lbs (91 t) of cod died. A sample (n=193) of these fish, obtained by divers, had a mean length of 59 cm (range 35-95 cm). The fish were to all appearances healthy and in good condition. Harp seals were reported in the area and some of the larger cod in the sample had bites taken from their bellies. In early February, 1999, a small number of cod were found frozen in the ice at Virgin Arm. Seals were in the area.

Reports from southwestern Bonavista Bay are similar but include more observations of predation by harp seals. On December 30, 1997, cod were observed chasing herring very close to shore in Cannings Cove. In early February, 1998, many dead cod were observed in Southern Bay Reach. Many harp seals were reported in the area. From February 28 to March 3, 1998, cod were seen swimming with fins above the surface, and 200 lbs of cod were found dead on the shore. Seals were reported in the area and an observer reported seeing a seal taking a bite out of a cod's belly. On January 11-13, 1999, many cod were observed swimming near the surface at Cannings Cove and Jamestown. Seals were again seen in the area and an observer reported seeing seals with cod in their mouths, shaking the cod and tearing out the guts. On January 20, 1999, an observer saw a very large number of seals near Deer Island (at the headland between Goose Bay and Sweet Bay) coming to the surface with cod in their mouths. They would take a clean cut out of the belly, taking the liver but leaving the gonad. As reported by The Telegram (St. John's, NL, February 23, 1999), in February 1999 seals were observed preying on cod in a small cove on Deer Island. The seals would shake the cod "and the gut would stay in the mouth and the fish would fly off". The presence of large numbers of dead cod on the bottom was confirmed by a diver. One cod recovered with a large bite from its belly was reported to be about 3 feet (91 cm) long. Divers harvesting sea urchins reported seeing large numbers of dead cod on the bottom in many parts of southwestern Bonavista Bay during the late 1990s.

A1.3 Stock relationships of cod in the inshore

A1.3.1 Did some migrating cod from offshore remain inshore?

It has been suggested that some of the cod that at one time migrated between the offshore and the inshore remained in the inshore in the early to mid-1990s, contributing to the dense aggregation first found in Smith Sound, Trinity Bay, in 1995 and to the high catch rates experienced by participants in the sentinel surveys. There have been several variants of this hypothesis.

One suggestion was that a major progressive change in migration behavior occurred in the early 1990s, resulting in cod remaining inshore during the entire year.

A second variant was proposed by G. Rose (Memorial University of Newfoundland, St. John's, Canada),who has been quoted as noting that there were almost no older fish in the northern cod population by 1992, and that it is possible that the survivors, mainly younger fish, came inshore and remained there (The Evening Telegram, St. John's, NL, 24 March 1996, p. 13; Kurlansky 1997, p. 203).

A third variant was proposed by Taggart (1997), who noted that an aggregation of cod that had been found in the North Cape area of Division 3L each year during the autumn research bottom-trawl surveys was last detected in 1993 and that the large aggregation of cod in Smith Sound was first detected in spring 1995. Based on these observations and the results of genetic and parasite studies, Taggart (1997) hypothesized that "the large aggregations of cod observed in recent years in the Random Island region of Trinity Bay may be those that would normally aggregate offshore in the North Cape region but for some reason have ceased their normal migration pattern to offshore for winter." He noted that this hypothesis could be tested by sampling the large aggregation in Smith Sound and comparing it genetically with fish sampled in the offshore.

The above three variants of the altered migration hypothesis differ with respect to timing. The change could have occurred in the early 1990s when most fish disappeared from the autumn research surveys, about 1992-1993 when cod disappeared from the migration corridor east of Bonavista Bay as recorded during spring-summer acoustic studies, or about 1994 when the last aggregation of cod disappeared from the autumn research surveys. If the change occurred early in the 1990s, then a very large quantity of cod could have been involved and these cod should have been comprised largely of the 1986 and 1987 year-classes. With increasing delay in the change, the quantity of cod available to remain inshore would decline and the age classes would be more recent.

The data available for testing the altered migration hypothesis are limited. The only sources of information on cod of commercial size in the inshore between 1991 and 1995 are the small fishery in 1992 prior to declaration of the moratorium on July 2, food fisheries in 1992-1994, bycatch in fisheries directed at other species, and the research being conducted in the arms of western Trinity Bay.

As noted above, autumn bottom-trawl surveys in the late 1980s were dominated by the 1986 and 1987 year-classes, which seemed to disappear very rapidly in 1991 and 1992. If these cod migrated to the inshore and remained there, then inshore catches and catch rates might be expected to be high and dominated by these year-classes. The 1991 inshore fishery, which was the last fishery to be unrestricted, was indeed dominated by the 1986 and 1987 year-classes, but the total catch in 1991 was dramatically lower than that in 1990, especially north of Division 3L (Baird et al. 1992a). This decline in inshore catch was not consistent with the suggestion that a large quantity of fish remained inshore. In 1992 the inshore catch, taken mainly by a "recreational fishery" using jiggers or baited hooks, was small and composed of mainly the 1985-1987 year-classes, with the 1987 year-class dominant (Bishop et al. 1993). "In both 1991 and 1992 there were some indications, based on the commercial and recreational fisheries, that cod may have remained in inshore waters later than usual and in significant numbers. During the autumn surveys, time was allotted for limited coverage (using the bridge sounder to detect fish and trawling where possible) of those areas which are not normally included in the regular survey area. The results indicated that very few cod were encountered in the inshore areas surveyed" (Bishop et al. 1993, p. 3). It may be noted, however, that experience in the late 1990s showed that cod may be shoreward of the area that can be surveyed by large vessels.

In 1993 there was a food fishery with no restrictions on season or quantity of fish taken. There is considerable uncertainty about how much fish was taken. The catch from recreational fishing and by-catch was mainly of the 1987-1989 year-classes, with the 1989 year-class at age 4 comprising 45% by number (Bishop et al. 1994). In 1994 there was a food fishery of just 1300 t. Based partly on the poor results of the 1993 food fishery (and to prevent large amounts of fish being taken) (Kulka et al. 1995a), the 1994 food fishery was limited to five Friday/Saturday periods in August and September. Most participants considered the food fishery to be a failure and it was closed a week early because of small fish and low numbers in the catches (Bishop et al. 1995; Kulka et al. 1995a). The catch from the recreational and by-catch fisheries in 1994 was mainly from the 1989 and 1990 year-classes, with the 1989 year-class at age 5 comprising 43% by number (Bishop et al. 1995). One should not place much weight on the performance of food fisheries, since much of the effort was by non-professionals and the gear was restricted to hook and line. Nevertheless, the poor results in the 1993 and 1994 food fisheries and the dominance of the 1989 and 1990 year-classes (rather than the 1986 and 1987 year-classes) are not consistent with the hypothesis that the fish that disappeared from the offshore moved inshore and remained there.

In 1995 much more information became available from surveys in Smith Sound and catches from the sentinel surveys. The 1990 year-class was dominant in Division 3K, whereas the 1989 and 1990 year-classes were both strong in Division 3L, with the 1989 year-class more prominent toward the south (Davis 1996; Brattey 1997; Lilly et al. 1998a). These results indicate that the high catch rates in the sentinel surveys were not supported by the fish that disappeared from the offshore surveys in approximately 1990-1992. It is possible, however, that there was a change in migration pattern somewhat later as postulated by Rose and Taggart (as cited above). However, once again the match in year-classes is not correct. The bulk of the fish inshore in the mid-1990s was represented by the 1989 and 1990 year-classes, both of which had been weak at age 3 in the offshore bottom-trawl surveys. There remains the possibility that individuals of the 1989 and 1990 year-classes found inshore in the mid- and late 1990s were recruited from offshore spawning and failed to migrate offshore after spending their first few years inshore.

The age compositions from the sentinel surveys (Lilly et al. 2003), commercial fisheries (Lilly et al. 2003) and samples of cod from Smith Sound (Porter et al. 1998; Rose 2003) are consistent with the hypothesis that the buildup of biomass in the inshore during the 1990s was largely due to the recruitment and individual growth of the 1990 and 1992 year-classes. These year-classes appear to have been very weak in the offshore.

A1.3.2 Tagging

Inshore tagging experiments prior to the late 1980s were conducted during the summer and autumn (Templeman 1974, 1979), and thus are not helpful in testing the hypothesis that there are inshore components that are distinct from components that migrate to the inshore from offshore. Recoveries from these experiments came from both the inshore and the offshore.

Tagging studies, conducted during the post-moratorium period while the overall stock size has been extremely low (Brattey et al. 2001), indicate that the inshore of 3KL is currently inhabited by at least two groups of cod: (1) a northern resident coastal group that inhabits an area from western Trinity Bay northward to western Notre Dame Bay and (2) a migrant group from inshore and offshore areas of 3Ps that moves into southern 3L and less commonly into northern 3L and 3K during late spring and summer and returns to 3Ps during the autumn. Only a small number of tagged cod from 3Ps were caught north of Trinity Bay. The tagging also indicates considerable movement of cod among Trinity, Bonavista and Notre Dame bays.

It is not known if there is currently movement between the inshore and the offshore in 2J3KL. Very few tags have been applied to cod in the offshore in recent years because no aggregations sufficiently large to warrant tagging have been located. In addition, there has been only one reported offshore recapture of a cod tagged inshore after the mid-1990s. Of course, any conclusion about the current existence or absence of inshore-offshore migration is tempered by the fact that there has been no directed fishery for cod in the offshore during this period, so recaptures could come only from fisheries directed at other species, and the by-catch of cod from these other fisheries is thought to be small relative to the cod-directed inshore catch.

A1.3.3 Genetics

There are two conflicting interpretations of genetic studies. One is that cod in the inshore and offshore are genetically distinct from one another; the other is that there is no differentiation among groups of 2J3KL cod. These differences originate in part in methodology.

The results of studies employing microsatellite loci are interpreted to support the existence of sub-stock structure between the inshore and the offshore and in various areas of the offshore (Bentzen et al. 1996; Ruzzante et al. 1996, 1997, 1998, 1999, 2000; Taggart et al. 1998; Beacham et al. 2002). Substock structure at the level of bays is less strongly supported. Beacham et al. (2002) summed up their findings by stating that northern cod conforms to an isolation-by-distance structure, with cod from more distant locations tending to be more distinct.

In contrast to the studies with microsatellites, the results of studies with mitochondrial DNA provide no evidence of substock structure within 2J3KL (Pepin and Carr 1993; Carr et al. 1995). The conflicting interpretations of stock structure are not just a consequence of the use of different methodologies. Carr and Crutcher (1998) state that "re-evaluation of (the) microsatellite data supports the conclusion of extremely limited genetic differentiation among populations in the Northwest Atlantic". Those who support the interpretation of considerable substock structure contend that the mitochondrial DNA approach lacks the ability to detect the structure that is there.

Neither interpretation of the genetic data would preclude the possibility that functional subpopulations exist without significant genetic differentiation.

An important question is whether the fish currently inshore can contribute to the recovery of fish in the offshore. Beacham et al. (2002) contend that "given the population substructure … detected between most inshore and offshore areas, and among offshore areas themselves, the likelihood that the inshore-spawning stock will contribute to offshore recovery is low."

A1.3.4 Productivity

Since at least the mid-1990s, the aggregations sampled inshore by commercial fisheries, sentinel surveys, and research bottom-trawling in Smith Sound contain individuals that are much older and larger than those taken by research bottom-trawling in the offshore, especially in Divisions 2J and 3K. This supports the contention that there has been little movement of adult cod from the inshore to the offshore in recent years.

References

The references in this Appendix are included in the list at the end of the major portion of this paper.

Appendix 2. Comments regarding the COSEWIC assessment of 2J3KL cod.

This Appendix does not attempt a critique of the COSEWIC assessment. It simply draws attention to two aspects of the statements regarding the extent of the decline.

The COSEWIC summary statement incorrectly summarizes the COSEWIC assessment

In its assessment summary, COSEWIC (2003) stated that the Newfoundland and Labrador population was designated as endangered based on the following. "Cod in the inshore and offshore waters (of this area), having declined 97% since the early 1970s and more than 99% since the early 1960s, are now at historically low levels."

While it is clear that there has been a severe decline in the cod in this area, the manner in which the values of "97%" and "more than 99%" are used in the summary text is inappropriate. The summary implies that there were analyses that provided these values over these specific periods. That is, the text implies that there were analyses that indicated that the population declined 97% from the early 1970s to about 2001, and by more than 99% from the early 1960s to about 2001. This is different from the computations described in the COSEWIC status report, as follows.

The decline of the Newfoundland and Labrador population was computed for the period 1968-2001 from the abundance of mature fish as estimated from sequential population analysis (SPA) of each stock. There is no SPA for 2GH cod. The decline in abundance of the 2J3KL and 3NO stocks combined was computed to be 97% (COSEWIC 2003, p. 30). (As noted in Section 3.2.1 of the present document, there is no recent accepted SPA for the 2J3KL cod stock as a whole. The COSEWIC analysis extended an SPA from the early 1990s, as reported in COSEWIC (2003, p. 60)).

Two estimates were provided for the decline in the 2J3KL stock alone (COSEWIC 2003, p. 60). Both estimates made use of data from the offshore bottom-trawl survey.
(1) One estimate was a computation of the decline in the survey catch rate over the period 1983-2001. The computed decline was 99.9%. This is greater than that reported in the present document (Section 3.2.3.1). (It may be noted that the high value from the 1986 survey was deleted from computations in the present document.)
(2) The second method used in the COSEWIC assessment started with the abundance of the mature portion of the stock for 1962-1992 as estimated by SPA, computed a log-log regression of survey spawner catch rate data against SPA abundance estimates (for the same age classes) for the years 1983-1992, and then used this regression to estimate numbers of individuals for the years 1993-2001 from the survey catch rate data in those years. The decline from 1968 to 2001, as computed by this method, was 97%. (As noted in the major body of the present paper (Section 3.2.1), the relationship between the survey index and the total stock abundance has changed since about the mid-1990s. The offshore bottom-trawl index does not reflect the densities and age/size composition of the cod that have been sampled and caught in the inshore since 1995.)

The COSEWIC assessment did not consider biomass estimates for the inshore of Div. 3KL

The COSEWIC assessment of 2J3KL cod was based in part on the 2001 stock assessment [as documented in a Stock Status Report (DFO 2001a) and supporting research documents (mainly Lilly et al. 2001)], a Stock Status Update in 2002 (DFO 2002a), and some preliminary analyses presented during the 2003 assessment meeting.

The COSEWIC assessment summarized evidence for a decline in populations in the inshore of eastern Newfoundland during the late 1990s and early 2000s (COSEWIC 2003, p. 29). The COSEWIC assessment mentioned DFO bottom-trawl surveys in the new inshore strata, hydroacoustic surveys in Smith Sound, sentinel survey catch rates, and the opinions of fish harvesters as recorded in a survey conducted by the Fish, Food and Allied Workers (FFAW) Union. The COSEWIC report correctly noted that all of these sources were indicating a downward trend.

While the COSEWIC report used data from the inshore to indicate the direction of population trend, it did not take biomass estimates for inshore cod into account when considering current status of either the 2J3KL stock alone or the Newfoundland and Labrador designated unit as a whole. The COSEWIC report did not provide the biomass estimates available from the hydroacoustic surveys in Smith Sound (DFO 2001a, 2002a), and it did not mention biomass estimates that were available from the mark-recapture (tagging) study (DFO 2001a). These estimates of the biomass of cod in the inshore of Div. 3KL clearly indicate that the 2J3KL stock as a whole had not declined by 99.9%.

The COSEWIC report was presumably written before the results of the 2003 assessment meeting (DFO 2003) became available. The assessment meeting report contained a mark-recapture estimate for one more year, giving a total of four years, and also contained an inshore SPA for the first time. A downward trend was evident in these two series as well. Nevertheless, the assessment meeting report was not entirely negative. There was evidence of improved recruitment, and projections based on the SPA showed an upward trend.

(It may be noted parenthetically that it has often been stated in the public media that the COSEWIC assessment demonstrated that the northern cod stock declined by more than 99.9%. Thus, if the total (3+) biomass was about 3,000,000 t in the early 1960s and the spawning biomass was about 1,5000,000 t (see Section 3.2.2.1), then the total biomass in about 2001 would be less than 3,000 t and the spawning biomass would be less than 1,500 t. These numbers are clearly too low, given the biomass estimates from the inshore (see Section 3.2.4). The estimate of a decline of more than 99.9% is excessive, and has been used by some people to question the validity of the COSEWIC assessment. This is unfortunate, because it draws attention away from the important message regarding the severity of the decline in the stock as a whole.)

References

The references in this Appendix are included in the list at the end of the major portion of this paper.

Appendix 3. The collapse of 2J3KL cod. Some thoughts on the role of the environment

[(The paragraphs in this Appendix have been extracted almost verbatim from Lilly and Carscadden (2002).]

A3.1 Changes in the ecosystem off southern Labrador and eastern Newfoundland

The ecosystem off southern Labrador and eastern Newfoundland has been characterised by a relatively small number of species, a few of which have historically occurred in high abundance (Bundy et al. 2000; Livingston and Tjelmeland 2000; Carscadden et al. 2001). The dominant fodder fish has historically been capelin, with Arctic cod more prominent to the north and sand lance (*Ammodytes dubius*) more prominent to the south on the plateau of Grand Bank. Herring (*Clupea harengus*) is found only in the bays and adjacent waters. These four species of planktivorous fish feed mainly on calanoid copepods and larger crustaceans, the latter being predominantly hyperiid amphipods to the north and euphausiids to the south. The dominant piscivorous fish has been Atlantic cod, but Greenland halibut (*Reinhardtius hippoglossoides*) and American plaice (*Hippoglossoides platessoides*) have also been important. Snow crab (*Chionoecetes opilio*) and northern shrimp (*Pandalus borealis*) have been the dominant benthic crustaceans. The top predators are harp seals (*Phoca groenlandica*) and hooded seals (*Cystophora cristata*), which migrate into the area from the north during late autumn and leave in the spring. Other important predators include baleen whales, most of which migrate into the area from the south during late spring and leave during the autumn. Additional immigrants from the north during the winter include many birds which spend the summer in the Arctic, and additional immigrants from the south during summer include short-finned squid (*Illex illecebrosus*), fish such as mackerel (*Scomber scombrus*) and bluefin tuna (*Thunnus thynnus*), and several species of birds.

The Labrador/Newfoundland ecosystem experienced major changes during the last two decades of the 20th century. Atlantic cod and most other demersal fish, including species that were not targeted by commercial fishing, experienced declines to very low levels by the early 1990s (Atkinson 1994; Gomes et al. 1995). In contrast, snow crab (DFO 2002b) and especially northern shrimp (DFO 2002c) surged during the 1980s and 1990s and now support the most important fisheries in the area. Harp seals increased in abundance from fewer than 2 million individuals in the early 1970s to more than 5 million in the late 1990s (Healey and Stenson 2000; Stenson, et al. 2002). Capelin have been found in much reduced quantities in offshore acoustic surveys since the early 1990s, but indices of capelin abundance in the inshore have not experienced similar declines, leaving the status of capelin uncertain and controversial (DFO 2000, 2001b).

The waters of eastern Newfoundland have been fished for centuries, primarily for Atlantic cod but with an increasing emphasis on other species during the latter half of the 20th century. These fisheries have undoubtedly had an influence on both the absolute abundance of some species and the abundance of species relative to one another. However, the role of the fisheries in structuring the ecosystem is often difficult to distinguish from the role of changes in the physical environment.

The marine environment off Labrador and eastern Newfoundland has experienced considerable variability since the start of standardized measurements in the mid-1940s (Colbourne and Anderson 2003; Colbourne 2003) (Fig. A3.1). A general warming phase reached its maximum by the mid-1960s. Beginning in the early 1970s there was a general downward trend in ocean temperatures, with particularly cold periods in the early 1970s, early to mid-1980s and early 1990s. Ocean temperatures started to warm in 1995. The decade of the 1990s experienced some of the greatest extremes, with particularly cold conditions in 1991 and very warm conditions in various years of the late 1990s. There have also been extremes within a year, as illustrated by the particularly cold winter and unusually warm summer/autumn of 2003.

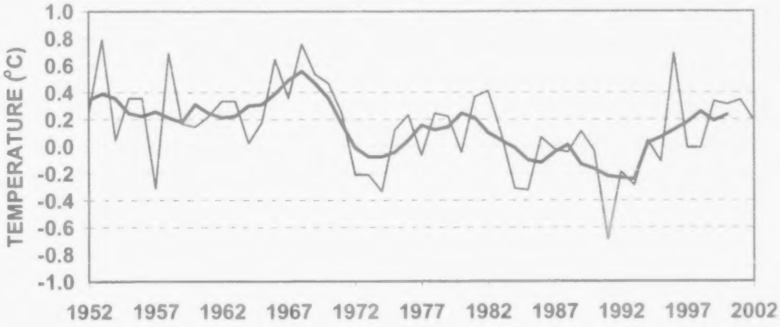


Fig. A3.1. An index of temperature. The light line shows the annual depth-averaged (0-176 m) temperature anomalies from Station 27, near St. John's. (See Fig. 4 for location of Station 27.) The heavy line is a 5-year running mean. (from Colbourne 2003) Additional indices of temperature and ice coverage are available.

The decline in water temperature during the last three decades of the 20th century was associated with an intensification of the Icelandic Low. An expression of this low that has commonly been used to correlate with physical and biological charateristics of the ecosystem is the sea-level air pressure difference between the Icelandic Low and the Bermuda-Azores High (the North Atlantic Oscillation or NAO). Off southern Labrador and northeastern Newfoundland, there is a well documented link between the positive phase of the NAO and intensified northwesterly winds, lower air temperatures, lower water temperatures and more extensive ice cover (Colbourne et al. 1994; Mann and Drinkwater 1994; Narayanan et al. 1995). These associations have become less clear since the late 1990s as the Icelandic low has been centred more to the east in some years.

Changes in the biological components of the ecosystem off northeastern Canada have been variously ascribed to overfishing, climate variability, changes in predation pressure or a combination of these factors. The relative importance of fishing and environment is difficult to determine for any species or group of species, so it is perhaps not surprising that the importance attributed to each has varied among studies. It is also perhaps not surprising, given the differences among species in the magnitude of fishery removals relative to stock size, that opinion tends to favour fishing as the dominant factor for some species and environment as the dominant factor for others. For demersal fish, there are many statements to the effect that declines were caused entirely by overfishing. Nevertheless, there is evidence that changes in oceanographic properties contributed to changes in distribution and declines in productivity (including decreased individual growth rate and possibly decreased recruitment and increased mortality). For crab and especially shrimp, it has been suggested that increases in biomass were simply a consequence of a release in predation pressure from Atlantic cod and perhaps other demersal fish, but again there is evidence that changes in oceanographic factors contributed to an increase in reproductive success. For capelin, most information supports the hypothesis that fishing had little impact on population dynamics, and that environmental factors were the primary determinant of stock size, well-being (growth and condition), distribution and timing of migrations.

A3.2 Environmental conditions and the collapse of 2J3KL cod

As with most heavily fished stocks, it is difficult to distinguish the influence of climate variability from the influences of intensive fishing and interactions with other species, both predators and prey. For the cod off Labrador and eastern Newfoundland, the fishery was clearly the major factor in the decline during the latter half of the 20th century. For the ultimate collapse, there is controversy as to whether there was a rapid but progressive decline from the mid-1980s onward or a precipitous decline during the early 1990s (Atkinson and Bennett 1994; Shelton and Lilly 2000). The former would imply that the estimates from research vessel surveys were severely positively biased for several years. The latter would imply that a very large quantity of fish unaccountably disappeared, either from greatly increased natural mortality or from greatly increased unrecorded fishing mortality (including perhaps both under-reported catches and non-reported discards). Many studies (e.g. Hutchings and Myers 1994a; Myers and Cadigan 1995; Hutchings 1996; Myers et al. 1996 a,b, 1997 a,b; Haedrich et al. 1997) have concluded that the collapse was caused entirely by fishing activity (landed catch plus discards). However, several authors point to various ways in which the decline in water temperature might have contributed to the collapse, either directly by reducing productivity (Mann and Drinkwater 1994; Drinkwater 2000, 2002; Parsons and Lear 2001) or indirectly by affecting distribution (Rose et al. 2000). See also Rice (2002) for an overview.

The severe decline of Atlantic cod in the Newfoundland-Labrador area seems to have occurred from north to south. On the northern and central Labrador shelf (Div. 2GH) catches of 60-90,000 t were reported in the period 1965-1969, but catches declined to less than 5,000 t in most years during the 1970s and early 1980s, to less than 1,000 t during the latter half of the 1980s and to zero in 1991. There appear to be no analyses of factors that contributed to the decline in this northern area. In the area from southern Labrador to the northern Grand Bank (Div. 2J3KL), catches declined during the 1970s, improved during the 1980s, and then declined precipitously in the late 1980s and early 1990s. The period of the collapse was accompanied by a dramatic change in distribution of Atlantic cod in Div. 2J, 3K and northern 3L. The autumn research vessel surveys, winter acoustic surveys and the distribution of the winter/spring trawler fleet all indicated that the fish disappeared first from the north and west, became increasingly aggregated near the shelf break in the south and east, and finally disappeared almost completely by 1994 (Baird et al. 1992b; Lilly 1994; Kulka et al. 1995b; Wroblewski et al. 1995b; Rose and Kulka 1999). There has been controversy regarding whether this change in distribution pattern resulted from a southward shift in distribution or a pattern of fish dying out in a sequence from north to south. Various analyses have been presented in support of the hypothesis that at least some of the cod shifted southward, possibly in response to a decline in water temperature (deYoung and Rose 1993; Rose et al. 1994; Atkinson et al. 1997; Rose et al. 2000) or a southward shift in the distribution of capelin (Rose et al. 2000). Indeed, Rose et al. (1994) indicated that this final shift in the late 1980s and early 1990s was part of a pattern of north/south displacements of several degrees of latitude in response to warming and cooling of water temperature. Other analyses found no support for the southward shift hypothesis (Hutchings and Myers 1994a; Hutchings 1996; Myers et al. 1996a). It is important to know whether a southward shift actually occurred, because it is postulated that such a shift made the cod more accessible to fisheries as the stock declined (Rose and Kulka 1999; Rose et al. 2000), and because the more southerly distribution placed the cod in a position that is hypothesized to be disadvantageous for successful reproduction (deYoung and Rose 1993; Rose et al. 1994; Rose et al. 2000).

Temperature and other oceanographic factors have been shown or hypothesized to have influenced various elements of productivity (recruitment, individual growth and mortality) in the Atlantic cod off southern Labrador and eastern Newfoundland. Recruitment may be affected by the magnitude of the spawning stock and two easily measured oceanographic variables, temperature and salinity. Numerous studies have demonstrated a positive association between spawning stock biomass and recruitment (e.g. Rice and Evans 1988; Myers et al. 1993a; Hutchings and Myers 1994a; Morgan et al. 2000). However, Drinkwater (2002) pointed out that both spawning stock biomass and recruitment experienced a long-term decline from the 1960s to the late 1980s, and that a statistical demonstration of the influence of spawning biomass on recruitment does not hold if the data are first-differenced to remove trends. With respect to environmental influences, there is expectation that recruitment in 2J3KL cod might be positively influenced by warm temperatures, because the stock is at the northern limit of the species' range in North America (Planque and Frédou 1999), but there have been conflicting reports of whether such a relationship can be detected (deYoung and Rose 1993; Hutchings and Myers 1994a; Taggart et al. 1994; Planque and Frédou 1999). Similarly, a reported relationship between recruitment and salinity (Sutcliffe et al. 1983) was subsequently supported (Myers et al. 1993a) and later rejected (Hutchings and Myers 1994a; Shelton and Atkinson 1994) as data for additional years became available. With respect to individual growth, a negative impact of temperature has been well documented (Krohn et al. 1997; Shelton et al. 1999). With respect to mortality, the possible influence of cold water is of considerable interest because of an apparent coincidence between the rapid disappearance of cod from research surveys and the low temperature and extensive ice cover of the early 1990s. While it seems unlikely that significant numbers of fish died as a direct consequence of exposure to cold water, there is still insufficient evidence to reject the possibility that the cold water and extensive ice cover led to a reduced duration of feeding opportunity, which itself led to poor body condition and death (Dutil and Lambert 2000; Lilly 2001).

The question of whether there was an increase in natural mortality in the 1980s and early 1990s, and whether any such increase was related to environmental factors, is of great importance to understanding the dynamics of Atlantic cod and other demersal fish (Lilly 2002; Rice 2002). As noted above, it is difficult to account for all the Atlantic cod that disappeared from the system without invoking either a considerable increase in non-reported fishing mortality or an increase in natural mortality. A similar controversy surrounds the American plaice stock off Labrador and northeastern Newfoundland (SA 2 + Div. 3K), which declined to a very low level through the 1980s and early 1990s, a period during which reported catches were low (Bowering et al. 1997). Hutchings (1996) presented a scenario illustrating how substantial quantities of American plaice may have been caught and discarded in the Atlantic cod fishery, but Morgan et al. (2002) re-examined his analyses and concluded that fishing was not the cause of the decline. Most other species of demersal fish, including many of no commercial value, declined dramatically through the same period. It has been stated that fishing was the cause of all these declines (Haedrich and Fischer 1996; Haedrich and Barnes 1997, Haedrich et al. 1997). However, the available data consist of indices of stock abundance and estimates of removals by the fishery, with little or no information on discards and incidental fishing mortality, so it is not possible to ascertain either the number of fish initially in the water or the number killed by the fishery. Under such circumstances, it remains somewhat a matter of faith to ascribe the declines entirely to fishing and to reject the possibility that natural mortality increased.

References

The references in this Appendix are included in the list at the end of the major portion of this paper.

Appendix 4. Factors influencing the re-building of 2J3KL cod

(The overview in this Appendix was initially prepared for the Canada – Newfoundland and Labrador Action Team for Cod Recovery.)

The question of why cod stocks have not recovered since the imposition of moratoria in the early 1990s was addressed during the February 2003 cod zonal assessment meeting (Rice and Rivard 2003; Rice et al. 2003). Some generalities were identified. However, there is as yet no detailed critique of all factors that have been postulated to have been instrumental in impeding the recovery of 2J3KL cod. This section provides a brief overview of some of the processes and agents that may be affecting reproduction, growth and mortality. In some cases, a distinction is made between the offshore and the inshore.

A4.1 Reproduction (to the start of the benthic juvenile stage)

The level of recruitment to the start of the benthic juvenile stage will be affected by the number and quality of eggs produced by the stock, and by the survival of eggs, larvae and pelagic juveniles.

A4.1.1 Reproduction in the offshore

As noted in the status section, recruitment in the offshore has been very low since the early 1990s.

A4.1.1.1 Egg production

It is expected that the number of eggs produced by the stock will be small because of the low spawning stock biomass (SSB) and the high proportion of first-time spawners in the population. That is, the expectation of a strong year-class is low.

We would like to know whether the number of recruits produced by the stock during the collapse period has been as high as might be expected, given the low stock size. That is, are there factors other than the low SSB contributing to low recruitment to the early juvenile stage?

There are suggestions that fishing activity has disrupted the spawning behaviour of cod and thereby caused a reduction in the number and quality of fertilized eggs released into the sea. It is known that trawling disrupts spawning aggregations (Morgan et al. 1997) and chronic stress in the laboratory can reduce reproductive output (Morgan et al. 1999), but it is very difficult to determine whether trawling on spawning shoals of northern cod has been sufficiently disruptive to reduce their spawning success. It may be noted that there has been no directed trawling for cod during the moratorium period, but shrimp trawlers may operate in areas where cod are spawning.

There is evidence that populations have lower reproductive success at low population size due to a variety of phenomena that are not in play when the population is larger. These phenomena, collectively referred to as Allee effects, include difficulty in finding a mate and breakdown in social structure and migration patterns. It is not known if such effects have been influential in 2J3KL cod.

A4.1.1.2 Survival of eggs and larvae

Survival of cod eggs and larvae is likely to vary over time and space. The low number of spawners since the mid-1990s and their relatively small size will reduce the temporal and spatial scale over which the eggs are released, and contribute to a lower likelihood that a good proportion of eggs and larvae will find suitable conditions. A more explicit variant of this concept is the "right site" hypothesis advanced by DeYoung and Rose (1993). They contend that Hamilton Bank is an advantageous site for release of northern cod eggs, and that the more southerly distribution of cod during the 1990s was disadvantageous because of an increased likelihood that the eggs would be advected off the shelf.

Predation on cod eggs and larvae: It has been hypothesized that part of the reason why large, dominant species such as cod have been successful is that their adults crop down forage species. When abundance of the adults of the large species is severely reduced, then the forage species may increase in abundance due to reduced predation pressure. The forage species then keep the once dominant piscivore in low abundance by preying on its early life stages (eggs, larvae or juveniles) or by competing with them for food. There is not a lot of direct dietary evidence for such a phenomenon, but there is evidence for predation by herring and sprat on cod larvae and especially cod eggs in the Baltic Sea. For the southern Gulf of St. Lawrence, a reciprocal relationship between biomass of pelagic fish (herring and mackerel) and recruitment of cod supports the hypothesis that predation on early life stages is impeding recovery of the cod in that area (Swain and Sinclair 2000).

For the 2J3KL area, there is no evidence that any planktivorous finfish has benefited from the collapse of cod, but there has been a surge in snow crab and especially northern shrimp. It is not clear that the surge of these species was related solely to a release in predation pressure from cod (Lilly et al. 2000b), but in any event there remains the possibility that snow crab larvae and northern shrimp may be preying on cod eggs and larvae. In addition, Anderson and Rose (2001) drew attention to the increase in Arctic cod off eastern Newfoundland during the 1990s (Lilly and Simpson 2000). Although this increase is more likely to have been related to a decrease in water temperature than to a decline in predation from cod, there remains the possibility that Arctic cod might have had a negative influence on cod because they competed with the cod for food or they preyed on larval or early juvenile cod. In the past few years, mackerel and billfish, both of which are summer migrants from the south, have been more abundant in inshore Newfoundland waters than they were for many years, and these also could be preying on cod eggs and larvae. In summary, there is a possibility that an increase in mortality rate of cod eggs and larvae is contributing to the non-recovery of 2J3KL cod, but there are no diet data to test the hypothesis, and there has been no increase in those species (such as capelin and herring) that are most likely to prey on cod eggs and larvae.

Prey for larvae and pelagic juveniles: There is very little information on trends in the abundance and distribution of the prey of larvae and pelagic juveniles. There have certainly been changes in the overall biomass and species composition of the phytoplankton and zooplankton in the waters off Labrador and eastern Newfoundland, but the implications for cod are not well understood.

The information that bears most directly on this issue comes from pelagic net surveys conducted during 1994-1999 (Colbourne and Anderson 2003). It was found that the biomass of zooplankton and the abundance of pelagic juvenile cod on Grand Bank were very low in 1994, but that they increased as the waters warmed during the mid- to late 1990s. The abundance of pelagic juvenile cod did not increase until 2 years or so after the zooplankton started to increase. This is interpreted as evidence that the cold conditions of the early 1990s were inhibiting recruitment of cod, and that warm conditions were necessary but not sufficient for improved recruitment. Good feeding conditions were also necessary.

A4.1.2 Reproduction in the inshore

The time-series of the sentinel surveys and the inshore SPA are too short to assess whether recruitment since 1992 has been good or bad relative to levels before 1990. Recruitment was better in the late 1990s than in the mid-1990s. This may have been related to the warmer water in the late 1990s, as discussed above.

A4.1.3 Summary of factors affecting eggs, larvae and pelagic juveniles

As noted above, the major factor contributing to poor recruitment to the end of the larval stage has been the very low level of the spawning stock biomass (SSB). There is evidence from pelagic surveys that temperature and food availability for larvae or pelagic juveniles have also been important.

The pelagic surveys have been discontinued. It is difficult to detect factors affecting specific early life stages in the absence of surveys directed at obtaining indices of abundance for those stages. Note that it would be possible to determine if the production of older recruits (age 2 or 3) were good or poor relative to the size of the SSB if there were an accepted SPA spanning the pre and post-collapse periods. In such circumstances, one might use the ratio of recruits to SSB (or some such index) to assess the productivity of the stock.

A4.2 Individual growth

Prey: The trend in biomass of capelin, historically the major prey of cod in 2J3KL, has been uncertain since the late 1980s. (Biomass estimates from hydroacoustic surveys in the offshore have been much lower since the early 1990s compared with the 1980s, but indices of capelin biomass from the inshore have not shown such extensive declines.) Some studies of cod condition and feeding indicate that cod may not be faring well in certain seasons and areas, and that this is due to low availability of capelin (Rose and O'Driscoll 2002). Other studies and observations do not suggest any concerns at present about cod growth or condition (Lilly et al. 2003). Whatever the present circumstances, there remains concern that there may not be sufficient capelin to support a recovery of the cod stock, especially in the offshore and in the north (DFO 2003). (See Appendix 6 for additional information on capelin.)

A4.3 Natural mortality

A4.3.1 Natural mortality in the offshore

As noted in section 8 of the main paper, the total mortality of fish in the offshore has been very high since the start of the moratorium. Reported by-catches in the offshore have been small, so considerable attention has focused on the possibility that natural mortality is high. Most attention has focused on the impact of predators.

A4.3.1.1 Predators

Most attention has focused on seals. The harp seal population has increased since the 1970s and estimates of consumption of cod by harp seals since the early 1990s appear high compared with the perception of cod stock size. It appears that predation by harp seals could be the major factor contributing to high mortality in the offshore, but little is known about harp seal diet in the offshore. Hooded seals may also be important predators on cod, but there are no estimates of their removals. There are also no estimates of removals by cetaceans, including minke whales and various toothed whales (e.g. pilot whales and porpoises). Various finfish are also known to feed on juvenile cod, but these species are depressed in abundance.

A4.3.1.2 Prey

As noted above, some scientists are of the opinion that cod have been in poor condition in recent years, and that this has been caused by low availability of capelin. It is postulated that this low condition has resulted in higher over-wintering or spawning mortality.

A4.3.2 Natural mortality in the inshore

As noted in section 8 of the main paper, tagging studies provide evidence for high natural mortality of adult cod in the inshore, especially in 3K.

A4.3.2.1 Cold water and ice

A mass natural mortality of about 800 t of cod occurred in Smith Sound during April 2003. Although the cause of this event is not fully understood, it was clearly related to unusually cold temperature (Colbourne et al. 2003). This was an important event, but the recorded deaths amount to less than 5% of the biomass of cod that was estimated to be in Smith Sound during an hydroacoustic survey in January 2003.

Mass mortalities in shallow water occurred in several locations in Notre Dame Bay and Bonavista Bay during 1998-2000 (Lilly et al. 1999, 2001). These mortalities are understood to have been much smaller than the mass mortality in Smith Sound, and occurred when the inshore populations were larger. It is therefore thought that they would not have had a significant impact on the inshore cod as a whole, but they may have been important for local components that were much smaller than the Smith Sound population. The relative importance of seals and ice in causing mortality during these events is discussed in section A4.3.2.2.

A4.3.2.2 Predators (notably seals)

There are numerous predators on cod in the inshore, including squid, several species of fish, and cetaceans. However, most attention has been focused on harp seals because of their abundance and large individual size.

The following discussion of seal-cod events is taken from Lilly (2004).

Reports of cod in shallow water became frequent in the winters of 1997-1998, 1998-1999 and 1999-2000. These reports came primarily from two areas: Notre Dame Bay on the northeast coast and southwestern Bonavista Bay on the east coast. [See Lilly et al. (1999) for a brief catalogue of some of the earlier events.]

Reports from Notre Dame Bay included the following. From January 11 to approximately January 16, 1999, cod were found dead and dying in and below ice in Virgin Arm. It was estimated by Fishery Officers, who interviewed divers and other people who harvested the fish, that perhaps 200,000 lbs (91 t) of cod died. A sample (n=193) of these fish, obtained by divers, had a mean length of 59 cm (range 35-95 cm). The fish were to all appearances healthy and in good condition. Harp seals were reported in the area and some of the larger cod in the sample had bites taken from their bellies.

Reports from southwestern Bonavista Bay were more frequent and included numerous descriptions of predation by harp seals on cod. In early February, 1998, many dead cod were observed in Southern Bay Reach. Many harp seals were reported in the area. From February 28 to March 3, 1998, cod were seen swimming with fins above the surface, and 200 lbs of cod were found dead on the shore. Seals were reported in the area and an observer reported seeing a seal taking a bite out of a cod's belly. On January 11-13, 1999, many cod were observed swimming near the surface at Cannings Cove and Jamestown. Seals were again seen in the area and an observer reported seeing seals with cod in their mouths, shaking the cod and tearing out the guts. On January 20, 1999, an observer saw a very large number of seals near Deer Island (at the headland between Goose Bay and Sweet Bay) coming to the surface with cod in their mouths. They would take a clean cut out of the belly, taking the liver but leaving the gonad. As reported by The Telegram (St. John's, NL, February 23, 1999), in February 1999 seals were observed preying on cod in a small cove on Deer Island. The seals would shake the cod "and the gut would stay in the mouth and the fish would fly off". The presence of large numbers of dead cod on the bottom was confirmed by a diver. One cod recovered with a large bite from its belly was reported to be about 3 feet (91 cm) long.

Observers say that they never before experienced incidents such as the above.

The following is a brief overview of information gleaned from newspaper accounts and reports by fishery officers and DFO scientific staff.

Observations of seals preying on cod by belly-feeding have been reported mainly from early winter to early spring and mainly from Notre Dame Bay (NDB), Bonavista Bay and Trinity Bay.

There have been several instances in which divers have reported cod lying on the bottom with holes in their bellies. There have been several well-documented incidents from eastern Notre Dame Bay and southwestern Bonavista Bay in which cod have been found milling about lethargically in cold shallow water. In some of these incidents seals have been observed on the periphery, especially near dawn and dusk. The most notable such incidents occurred at Virgin Arm in NDB in 1999 and at several locations in southwestern Bonavista Bay in 1998-2000. These incidents have generally occurred adjacent to deep water where the cod may have been overwintering. Some people think the cod were herded by the seals into the shallow water, where some of the cod then died from seal predation and perhaps from exposure to the cold water and ice. Cod have been harvested in a few of these situations and most such cod have been lethargic but alive. If cod die from exposure to cold and ice after fleeing from seals, then such mortality may be considered "fatal harassment" (McLaren et al. 2001). Another possible cause of incidents where cod have been found milling about in cold shallow water is that the cod entered the shallow water for some other reason, such as the pursuit of prey. Seal predation associated with such incidents might be opportunistic. Observations of belly-feeding continue to the present. There have been no recent reports of "events" as dramatic as those that occurred during 1998-2000.

There is evidence that natural mortality of adult cod has been high in Notre Dame Bay and Bonavista Bay. The opening of a cod-directed fishery in the inshore during 1998-2002 provided an opportunity to conduct tagging studies with the intent of estimating exploitation rates. After several years it became apparent that the returns of tags applied during specific tagging studies had declined very rapidly over time in Div. 3K (Brattey and Healey 2003). This trend was less dramatic in Bonavista Bay, and even less so in Trinity Bay. An exploration of the magnitude of natural mortality that would be consistent with such rapid disappearance of fish (Cadigan and Brattey 2003) concluded that natural mortality was likely as high as 55% per year in Div. 3K and 33% in Div. 3L as a whole

References

The references in this Appendix are included in the list at the end of the major portion of this paper.

Appendix 5. The role of predators, especially seals, in the dynamics of cod since the mid-1990s

[The overview in this Appendix was initially prepared for the Canada – Newfoundland and Labrador Action Team for Cod Recovery. It was written as a series of short paragraphs, and retains that style. G. Stenson (Fisheries and Oceans Canada, St. John's, NL) provided some of the information.]

The predators of cod tend to change as the cod grow (Pálsson 1994; Bundy et al. 2000). Very small cod are eaten by squid, various groundfish (such as sculpins) and some seabirds. Larger juveniles are eaten by various groundfish (most notably Greenland halibut and cod), harp and hooded seals, certain toothed whales (e.g. harbour porpoise, pilot whales) and likely minke whales. Large cod probably have few natural predators, but seals can prey upon them by belly-feeding.

The predator that has received most attention is the harp seal. The harp seal population declined during the 1950s and 1960s because of heavy hunting and reached a minimum of fewer than 2 million individuals in the early 1970s. The population then increased to about 5.2 million by 1996 (Healey and Stenson 2000). Larger harvests in recent years have kept the population relatively stable at this level.

It has been estimated that harp seals consumed about 3,060,000 t of prey in 2J3KL and 3Ps in 2000. This is about 40% of the annual consumption of prey by the harp seal population. Approximately 50% of the annual consumption is taken in the Arctic and approximately 10% is taken in the Gulf of St. Lawrence.

Cod is a minor prey of harp seals (Hammill and Stenson 2000). The harp seal diet, as reconstructed from the hard parts of prey found in their stomachs, is mainly plankton-feeding pelagic fish. The dominant prey in 2J3KL are capelin, Arctic cod, sand lance and herring.

The quantity of cod consumed by harp seals has been computed using harp seal population numbers, energy requirements of individual seals, the average duration of seal occurrence within 2J3KL, the relative distribution of seals between inshore and offshore, and average diets compiled for the inshore and the offshore.

Based on the average diets, it was calculated that harp seals consumed 37,000 t of cod in 2000 (with a 95% confidence interval of 13,000 – 62,000 t) (Fig. A5.1).

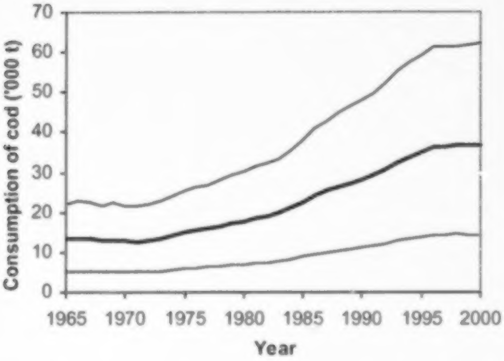


Fig. A5.1. Consumption (with 95% confidence intervals) of cod by harp seals in 1965-2000, based on diets averaged over 1982 and 1986-1998.

The only factor affecting among-year differences in these estimates of cod consumption is the estimate of harp seal population numbers. Consumption of cod has also been estimated using annual diets, but the large uncertainty associated with the yearly diets results in consumption estimates that are not significantly different from those computed using average diets.

Consumption estimates are imprecise due mainly to geographic, seasonal and annual variation in the diet. An important source of uncertainty is the relatively small number of harp seals that have been sampled in the offshore. In addition, the majority of those samples were obtained prior to the mid-1990s, and may not reflect more recent feeding.

The cod represented in the stomach contents of harp seals tend to be small, as indicated by the sizes of the cod otoliths (earbones). Most cod eaten from 1986 to 1996 were of ages 0 and 1, but in 1997 and 1998 older cod were dominant. It is thought that most otoliths come from cod that have been swallowed whole.

Larger cod may fall prey to belly-feeding, wherein the seal takes a bite from the cod's abdomen, consuming the liver and some of the other abdominal organs, but generally leaving the muscle and head. Instances of belly-feeding will usually not be detected by stomach content analysis. The weight of fish killed during such an incident is much greater than the weight of fish consumed.

Observations of belly-feeding have been reported mainly from early winter to early spring and mainly from Notre Dame Bay (NDB), Bonavista Bay and Trinity Bay (Lilly et al. 1999). There have been numerous reports of seals seen biting the abdomen of a cod, and there have been several instances in which divers have reported cod lying on the bottom with holes in their bellies. There have been several well-documented incidents in which cod have been found milling about lethargically in cold shallow water. In some of these incidents seals have been observed on the periphery, especially near dawn and dusk. The most notable such incidents occurred in Virgin Arm in NDB and several locations in southwestern Bonavista Bay in 1998-2000. These incidents have generally occurred adjacent to deep water where the cod may have been overwintering. Some people think the cod were herded by the seals into the shallow water, where some of the cod then died from seal predation and perhaps from exposure to the cold water and ice. Cod have been harvested in such situations and most such cod have been lethargic but alive. If cod die from exposure to cold and ice after fleeing from seals, then such mortality may be considered "fatal harassment" (McLaren et al. 2001). Another possible cause of incidents where cod have been found milling about in cold shallow water is that the cod entered the shallow water for some other reason, such as the pursuit of prey. Seal predation associated with such incidents might be opportunistic. Observations of belly-feeding continue to the present. There have been no recent reports of incidents as dramatic as those that occurred during 1998-2000.

Analyses of survey data indicate that cod in the offshore of 2J3KL have experienced very high mortality since at least the mid-1990s (Lilly et al. 2003). Very few cod survive beyond about age 5. There is insufficient direct evidence to determine incontrovertibly whether this high mortality is associated with fishing, poor condition, predation or some other factor. However, recorded by-catches of cod in domestic and foreign fisheries for other species have been small, and most information on body size indicates that the fish have not been in unusually poor condition in recent years. Thus, it has been concluded (DFO 2003) that the high abundance of harp seals at a time of low cod abundance, together with the estimates of cod consumption by seals, indicate that predation by harp seals is a factor contributing to the high total mortality of cod in the offshore. It must be recognized, however, that only a very small number of harp seals have been sampled in the offshore, and that there was only a trace of cod in their stomachs.

Analyses of tag return data indicate that adult cod in the inshore of 3K and 3L have been experiencing high mortality in addition to that caused by fishing (Cadigan and Brattey 2003; Lilly et al. 2003). This mortality is higher in 3K than in 3L. It has been concluded (DFO 2003) that the continuing presence of cod in the stomach contents of harp seals sampled inshore, together with observations of belly-feeding on adult cod, indicate that predation by harp seals is a contributor to the high natural mortality of cod in the inshore.

Predation on cod by hooded seals is less well known. The current status of the hooded seal population is not known because there has not been a population survey since 1990. Analysis of the limited number of stomach samples collected in the late 1980s and early 1990s indicates that hooded seals could be important predators on cod (McLaren et al. 2001). However, there are no data to assess the diet of hooded seals in the offshore since the northern cod population collapsed during the early 1990s.

It has been suggested that seals might detrimentally affect cod by competing with them for food. For example, capelin has historically been the major food for cod, and it has been estimated that harp seals ate about 893,000 t of capelin in 2J3KL in 2000 (Stenson and Perry 2001). However, there are numerous other capelin predators, including squid, other groundfish (Greenland halibut, American plaice), baleen whales (humpbacks, fins, seis and minkes), and birds (gannets, murres, puffins, shearwaters) (Bundy et al. 2000; Carscadden et al. 2001). In addition, harp seals, cod and numerous other predators share other forage fish, such as herring, Arctic cod and sand lance (Bundy et al. 2000). The complexity of the food web, and our rudimentary understanding of its dynamics, make it very difficult to assess the benefit that would accrue to cod from specific reductions in the abundance of harp seals.

There is evidence that seals are important contributers to the high mortality experienced by cod in 2J3KL. It has been stated that seal population numbers should be reduced to promote the recovery of seals. Arguments for and against this stance fall within the realms of conservation, ethics and international law (Molenaar 2002, 2003).

It is often assumed that a reduction in the number of seals will result in a decrease in the consumption of cod by seals and consequently an increase in the abundance of cod. As discussed in considerable detail by McLaren et al. (2001), this seems sensible, at least in the short term. That is, a sharp reduction of seal predation on cod of commercial size would immediately increase their availablity to a fishery (or increase the size of the spawning stock). Similarly, a reduction of predation on pre-recruit fish might give enough short-term relief to permit substantially more recruits to contribute to the spawning stock. However, other outcomes are possible, especially in the longer term. It must be recognized that the number or weight of cod consumed by seals may depend not only on seal abundance and cod abundance, but also on the distribution and degree of aggregation of the cod and the availability of alternate prey for the seals. There is also the possibility that cod saved from predation by seals may die from some other cause before they can contribute to a fishery or to the production of more cod.

Contrary to the assumption in the paragraph above, it has been suggested by some that a reduction in seals might actually cause a decline in cod, because the seals consume other species that prey on cod. McLaren et al. (2001) found no evidence to support such a scenario.

The high mortality experienced by northern cod in recent years is a major impediment to recovery. However, even if survival can be substantially improved, the stock will take a long time to reach a spawner biomass level of (say) 300,000 tons. This is because the stock is starting from a very low level, the small spawner stock biomass implies little likelihood of strong year-classes during the early stages of recovery, and the stock has an inherently low population growth rate because of slow individual growth and relatively late age at maturity.

References

The references in this Appendix are included in the list at the end of the major portion of this paper.

Appendix 6. The role of prey, especially capelin, in the dynamics of cod since the mid-1990s

[The overview in this Appendix was initially prepared for the Canada – Newfoundland and Labrador Action Team for Cod Recovery. It was written as a series of short paragraphs, and retains that style. J. Carscadden (Fisheries and Oceans Canada, St. John's, NL) provided some of the information.]

Cod feed on a wide variety of prey (Lilly 1987). The major prey for small cod are planktonic crustaceans, notably hyperiid amphipods in the north and euphausiids on Grand Bank. For medium-size cod the major prey are schooling planktivorous fish. The most important of these is capelin, but Arctic cod are eaten in the north, herring are consumed in inshore waters, and sand lance are important on Grand Bank. Larger cod tend to feed on medium-sized fish and crabs, especially toad crabs and small snow crabs. Shrimp are consumed by a broad size range of cod. Cod also feed on smaller cod, but cannibalism is not an important aspect of the cod's diet.

The prey that has received most attention is capelin. The importance of capelin to cod has long been evident from the vast shoals of cod that once migrated into the traditional inshore fishing grounds to feed on capelin that had approached the coast to spawn. In addition, a compilation of diet data for a study of biomass flows (Bundy et al. 2000) concluded that capelin contributed about 60% of the diet of large (>35 cm) cod on an annual basis during 1985-1987. In recognition of such observations, early multispecies concerns focused on questions such as how much capelin could be harvested without reducing the proportion of the cod stock migrating inshore and without affecting cod productivity (for example, by causing a decline in cod growth).

Capelin has been considered a vital component of the ecosystem off Labrador and eastern Newfoundland. It is a dominant link between zooplankton and members of higher levels of the food web, including not only cod but invertebrates (notably squid), other fish (Greenland halibut, American plaice), marine mammals (harp and hooded seals and several species of whales) and marine birds (murres, puffins, gannets) (Bundy et al. 2000; Carscadden et al. 2001). Capelin occupys a similar role in other Arcto-boreal ecosystems (e.g. the Barents Sea and waters around Iceland).

Capelin was historically fished for bait, fertilizer, dog food and human consumption. Such domestic use may have reached 20-25,000 t annually.

Catches increased substantially when non-Canadian fleets began fishing capelin offshore (Fig. A6.1). Catches peaked in 1976 at about 250,000 t, but then declined rapidly. The non-Canadian fleet used midwater trawlers, and operated during the spring in Div. 3L and during the autumn in Div. 2J3K. The offshore 3L fishery closed in 1979, whereas the offshore 2J3K fishery continued at a relatively low level until 1991, after which it too was closed.

During the late 1970s Canadian fish harvesters started to fish mature capelin near the spawning beaches to supply a market for roe-bearing females. This fishery expanded rapidly, exhibited highest catches during the 1980s, and declined after 1990 (Fig. A6.1).

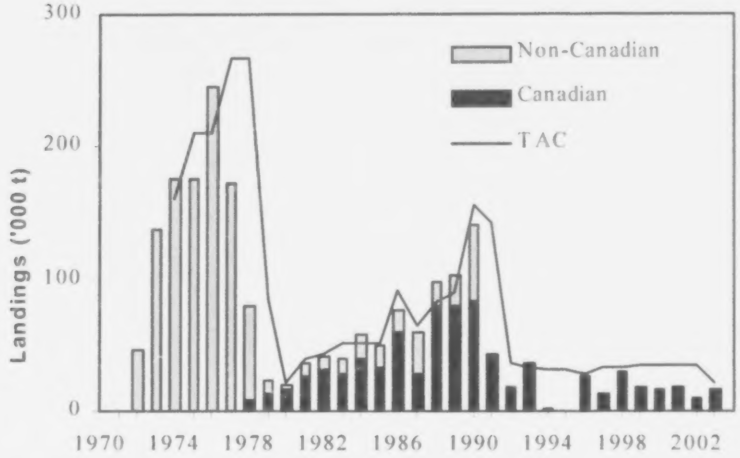


Fig. A6.1. Commercial landings and total allowable catches (TAC's) (thousands of tons) of capelin in 2J3KL. Landings are shown separately for Canadian and non-Canadian fleets. For many years capelin in SA2+Div. 3K were managed separately from those in Div. 3L.

Information on the status of the capelin stock is available since about the mid-1970s, but there is no single source of information that indicates the trend from that time to the present. The population was abundant during the mid-1970s, but declined during the late 1970s and then increased again during the 1980s. Since the early 1990s, the status of the stock has been highly uncertain (DFO 2000, 2001b). The spring offshore hydroacoustic survey in 1990 produced an estimate of 6.9 million t of capelin, whereas the estimate the following spring was about 0.1 million t. Hydroacoustic surveys and studies in the offshore have failed to find much capelin since that time. In contrast, capelin indices from the inshore (e.g. commercial catch rates; school areas derived from aerial surveys) did not show such precipitous declines.

Many inshore fish harvesters think that the capelin stock has been well below its historic abundance since the early 1990s. Others think the stock is not as severely depleted, particularly in certain areas.

Perception of capelin abundance may be influenced to some extent by the many changes in capelin biology that became apparent in the early 1990s. These include a reduction in average capelin size, late arrival in coastal waters and increased spawning in deeper water (Carscadden et al. 2002; Nakashima and Wheeler 2002). These and other changes in capelin biology were originally attributed to below normal sea temperatures during the early 1990s. However, the biological characteristics have not reverted to their former status, despite a warming during the latter half of the 1990s and early 2000s, so temperature may not have been the sole reason for the changes.

The potential for the capelin fishery to affect capelin abundance is an important consideration when one wishes to take measures to promote the recovery of cod. Many people think that the fishery has an important influence on capelin status. This perception may be based not only on the magnitude of landings, but on the dumping of males and the dumping of catches because of redfeed and other factors. However, capelin scientists concluded that there was no scientific evidence to support the perception that the capelin fishery in SA2+Div. 3KL had an impact on the population abundance of capelin (Carscadden et al. 2001). This conclusion was based on a review of information existing up to the end of the 1990s. There has been no scientific evaluation of stock status since 2000, and hence it is not possible to contemplate the extent to which exploitation has affected the capelin stock in more recent years (DFO 2001b).

The capelin stock does undergo substantial changes in biomass over time. These changes appear to be related primarily to changes in recruitment, which is influenced by wind patterns acting on spawning beaches and possibly temperature and other factors. The biomass is also influenced by the individual size of fish in the population. It has been estimated that even if there was no change in population number between the 1980s and the 1990s, the population biomass would be about 29% smaller in the 1990s due to the decline in weight of individual fish. It is also likely that the number and kind of predators could affect the survival rate of capelin (Carscadden et al. 2001).

Despite the perception of a strong dependence of cod on capelin, it has been difficult to demonstrate such a dependence with scientific data and analyses. This may be because the dependence is indeed weaker than thought, but it could also be because the data available for addressing such complex questions are insufficient and highly variable.

The role of capelin in the failure of northern cod to recover in the period since its collapse is controversial. Studies of cod condition and feeding in specific areas and seasons have been interpreted as indicating that cod have not been faring well in certain areas, most notably off southern Labrador, and that this has been due to low availability of capelin (Rose and O'Driscoll 2002). In contrast, the routine monitoring of cod during autumn research surveys in the offshore have not identified any problems with cod growth or condition in recent years (Lilly et al. 2003). Cod in the inshore appear to have been faring well. Whatever the circumstances of recent cod growth and condition, there is concern that there may not be sufficient capelin to support a recovery of northern cod to its former level of high biomass, especially in the offshore and in the north (DFO 2003).

Concerns regarding the inability of the cod stock to recover without high availability of capelin are based on the assumption that there is no species (or group of species) that can replace capelin in the diet of cod. In the Barents Sea, the growth rate and condition of cod declined considerably when capelin abundance declined during the latter half of the 1980s, but the well-being of cod declined much less during a second capelin decline during the mid-1990s. It is thought that there were more small individuals of other fish species in the Barents Sea in the mid-1990s than in the latter half of the 1980s, and that the cod were able to compensate for the low availability of capelin by preying on these other fish species rather than having to rely on crustaceans (especially hyperiid amphipods and euphausiids). In the northern cod stock area, there remains uncertainty about the status of capelin, but many people feel that the stock is less abundant than it was during the 1980s. There is no evidence that any other finfish has increased since the early 1990s when many characteristics of capelin changed. There has, however, been an increase in the abundance of snow crabs and especially northern shrimp. Before the collapse of the cod stock, both of these species were moderately important prey for cod (Lilly 1987, 1991). These species may be less valuable than capelin as prey for cod because they are digested much more slowly and have a lower fat content.

The intensity of feeding and diet composition of northern cod has been less well studied in recent years than formerly. Observations of diet have been made since the late 1990s in specific locations and times during hydroacoustic studies conducted by scientists at Memorial University, but the collection of cod stomachs during annual DFO bottom-trawl surveys was discontinued during the latter half of the 1990s after about 20 years of continuous sampling. This makes it almost impossible to discern long-term trends in the extent to which cod have been successful in finding not only capelin (Lilly 1994; O'Driscoll et al. 2000) and shrimp (Lilly et al. 2000), but also a broad variety of other prey. Consider, for example, the larger planktonic crustaceans, notably hyperiid amphipods and euphausiids. These groups have in the past been important contributers to cod diet, but we know almost nothing about the trends in their abundance and the success with which cod have been finding them in recent years. There is evidence from examination of capelin stomachs that euphausiids may have been less available in recent years than they were in the 1980s (Mowbray 2002).

Scientists advised in the late 1970s that total allowable catches of capelin be set at a conservative exploitation rate of 10% because of poor recruitment in capelin stocks at that time. The rationale for this conservative approach to exploitation was expanded in 1982 when concern was expressed for the effect that harvesting of capelin might have on cod and other predators (NAFO 1982). Canada has not had a reduction fishery for capelin. As a consequence, the fisheries for capelin off eastern Newfoundland and Labrador have been small relative to those in waters around Iceland and in the Barents Sea (Fig. A6.2).

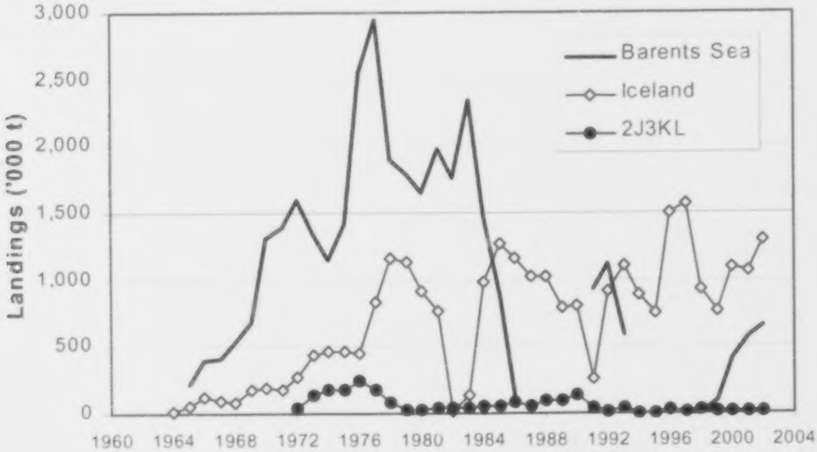


Figure A6.2. Catches of capelin off Labrador and eastern Newfoundland (2J3KL) compared with catches in waters around Iceland and in the Barents Sea. (modified and updated from Carscadden and Vilhjálmsson 2002)

Some of the text above discussed the extent to which the capelin fishery affected the status of the capelin stock, and thereby affected the quantity of capelin available to predators such as cod. There is also the question of the extent to which the capelin fishery might affect the immediate availability of capelin to cod. There have been no capelin fisheries in the offshore since 1991, so only the impact of the inshore fisheries need be considered. The inshore capelin fishery catches capelin only a short time before the capelin are ready to spawn. The immediate benefit to cod if those capelin are left uncaught is difficult to assess, because some of those capelin that are spared from the fishery would be eaten by predators other than cod (notably whales and birds). A high proportion of those capelin that survive the near-shore predator gauntlet die during or shortly after spawning. Only a portion of those dead capelin would be available to cod (because many remain on beaches, and there are many competitors for the dead capelin), and the duration of availability would be short, perhaps no more than a few hours or days. The capelin fishery would also reduce the quantity of spawn deposited on beaches and subtidal spawning grounds. Cod have been found to feed on subtidal capelin spawn, but spawn appears to be a minor component of their diet, so the impact of the capelin fishery on cod well-being through this process would seem to be small.

References

The references in this Appendix are included in the list at the end of the major portion of this paper.